A TEXTBOOK OF GEOLOGY

TEXTBOOK OF GEOLOGY

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JOHN WILEY & SONS, INC.

PART I

Physical Geology. By the late L. V. Pirsson. Third Edition revised by William M. Agar, Assistant Professor of Geology; Alan M. Bateman, Professor of Economic Geology; Carl O. Dunbar, Associate Professor of Historical Geology; Richard F. Flint, Assistant Professor of Geology; Adolph Knopf, Professor of Physical Geology; Chester R. Longwell, Professor of Geology. Revision Edited by Chester R. Longwell; vii + 488 pages, 6 by 9; 322 figures. Cloth.

PART II

Historical Geology. By Charles Schuchert. Second Edition, Rewritten and Enlarged; viii + 724 pages; 6 by 9; 237 figures in text; 47 plates; index and folding colored geological map of North America. Cloth.

Introductory Geology. By the late L. V. Pirsson and Charles Schuchert. Including "Physical Geology" and an outline of "Historical Geology." xii + 693 pages, 6 by 9; 395 figures in text; 26 plates; index and folding colored geological map of North America. Cloth.

Frontispiece

One of the most magnificent exposures of ancient marine sediments known. Eastward view up the Kaibab. Grand Canyon of the Colorado, Arizona. The horizontal Paleozoic strata (4300 feet thick) rest upon the contorted and peneplained Archeozoic. U. S. Geol. Surv. *V*, Archeozoic (Vishnu schist); *U*, thinned edge of Proterozoic (Unkar); *T*, *BA*, *M*, Cambrian (Tonto); *R*, *Ss*, *Ssh*, *C*, Mississippian and Pennsylvanian.

A TEXT-BOOK OF

GEOLOGY

PART I

PHYSICAL GEOLOGY

BY

LOUIS V. PIRSSON

Late Professor of Physical Geology in the Sheffield Scientific School of Yale University

THIRD EDITION

REVISED BY C. R. LONGWELL AND OTHER MEMBERS OF THE GEOLOGY DEPARTMENT, YALE UNIVERSITY

PART II

HISTORICAL GEOLOGY

BY

CHARLES SCHUCHERT

Professor Emeritus of Paleontology in Yale University and of Historical Geology in the Sheffield Scientific School

PART II

SECOND, REVISED EDITION

NEW YORK

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PREFACE TO PART II

In 1915, when the first edition of this text-book appeared, the author had had ten years' experience in teaching Historical Geology in the Sheffield Scientific School of Yale University. Since then he has continued his interest in the subject, teaching it until 1920, and has made almost daily annotations in his table copy of the first edition concerning the newer facts as they appeared in publications. It soon became a perplexing problem to know what to eliminate so as to keep the book within bounds, as one intended for beginners in Geology rather than for matured geologists. A few teachers present Historical Geology in 15 hours, most of them take from 28 to 35 hours, and now there is a strong tendency to extend the lectures and laboratory to 45 hours. Moreover, the fact that many American college students taking a year's work in Geology have had no preparation in Zoölogy or Botany makes it necessary to include in the book some description, however brief, of the fundamental structures of living plants and animals. To cut the dilemma arising from such diverse needs on the part of the teachers, the author has concluded, after seeking advice from many who are presenting the subject in our colleges, to include in the book too much material rather than too little. Accordingly the new edition is larger by some 80 pages. For the 45-hour course the book is about the right length, and it is thought that the instructors of the shorter courses will know best what parts to eliminate.

Historical Geology is a most fascinating study, since it includes not only the physical history of the earth from the time of its solar origin, but as well the orderly appearance and evolution of all its life. It is therefore as much a biological science as it is a geological one, bringing together, into a connected whole, facts from sources as diverse as Structural and Stratigraphic Geology, Paleontology, Biology, Oceanography, and Astronomy. And perhaps more than any other branch of the geological sciences, Historical Geology leads into Philosophy, in the search for the meaning behind the story which it presents.

Because of its practical application to the welfare of man, Zoölogy has a tendency to push Historical Geology out of the present-day

curriculum. Geologists should not allow this to come about, since Historical Geology proves man to be "the paragon of animals, the climax of evolution," and all who drink deeply of this science will be compelled to work out their own philosophy of happiness. If a full course in Historical Geology can not be given, it should at least have as much place in the curriculum as can be kept for it.

The material upon which this book is based has naturally been drawn from so many sources and has become so integral a part of the writer's fund of information that it is not easy to render complete acknowledgment. The well-known general treatises and works of Dana, Suess, LeConte, Chamberlin and Salisbury, Scott, Grabau Cleland, Coleman and Parks, Geikie, Kayser, Walther, Neumayr Credner, Jukes-Browne, Lapparent, and Haug are of course the main sources. Of great service have also been the more general works on paleontology of Zittel-Eastman, Osborn, Scott, and Williston; the zoölogies of Thomson, Parker and Haswell, Lull, and Weysse; the works on man by Sollas, Keith, Huxley, and Osborn; the histories of Zittel, Geikie, and Merrill; the treatises on oceanography by Krümmel, Murray and Hjört, and Johnstone; astronomy as presented by Hale, Abbot, and Moulton; Clarke's work on geochemistry; and, for stratigraphy, Willis' great and comprehensive *Index*. Papers and books dealing with more special phases of the subject have been included in the list of "Collateral Reading" at the end of each chapter, which forms a new feature of this edition. Finally, the wealth of fact and illustration in the works of the United States Geological Survey, the Geological Survey of Canada, and the New York, Maryland, Illinois, Ohio, Indiana, Minnesota, and other state surveys has been drawn upon freely.

The writer is also much indebted to the United States Geological Survey and to Professor Bailey Willis for the great help given in the making of the geological map of North America which accompanies the book.

In the preparation of this edition, as of the former one, the author received much aid from the late Professors Louis V. Pirsson and Joseph Barrell, and from his colleagues, Professors Herbert E. Gregory and Richard S. Lull. Special thanks are due to his associate, Doctor Carl O. Dunbar, whose teaching of the subject has enabled him to offer constructive criticism on all parts of the book. Professor C. K. Leith of Wisconsin, Professor Adolph Knopf of Yale, Doctor Willet G. Miller of Toronto, and Director W. H. Collins of the Geological Survey of Canada have helped much to improve the chapters on the Archeozoic and Proterozoic. Thanks are also

due to his friends, Doctors T. W. Stanton and W. T. Lee, for special aid in the Mesozoic chapters, John M. Clarke for help in various places, and George Grant MacCurdy for criticism of the chapter on man. Professor L. G. Westgate has made valuable suggestions in many places, and to Doctor A. K. Lobeck much is owed for the spirit of coöperation and the ability shown in depicting the physiography on six paleogeographic maps, another innovation in this edition.

Most of the pen drawings were made by Mr. William Baake, the remainder by Doctor Stanley C. Ball and Miss Lisbeth B. Krause. The author's acknowledgments are also due to the publishing firms of Macmillan, Scribner's, Ginn and Company, and Putnam, for the loan of illustrations.

To Miss Clara Mae LeVene the writer is especially grateful for her untiring helpfulness in both editions of this book, as well as in the second edition of Part I.

Finally, the author wishes to record his appreciation of the skill and patience shown by the Technical Composition Company in getting the book ready for the pressroom, and of the helpfulness and courtesy of Wiley and Sons during the preparation and publication of both editions.

CHARLES SCHUCHERT

Peabody Museum of Yale University,
New Haven, Connecticut,
August, 1923

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PART II

HISTORICAL GEOLOGY

BY

CHARLES SCHUCHERT

TEXT-BOOK OF HISTORICAL GEOLOGY

CHAPTER I

HISTORICAL GEOLOGY

In this volume is presented the procession of more important events, physical and vital, that the earth is known or believed to have gone through. It is a history of the earth, and more especially of North America, during the long geological ages, as read in the various kinds of rocks and in the organisms of the past, the fossils, which together make up its outermost shell.

Historical Geology, sometimes also called Stratigraphical Geology, brings together all that has been made known in the other departments of Geology and Paleontology. In arranging this knowledge, we elucidate the history of the earth from the earliest time of which geologic records are known down to the time of the present. As yet, however, our knowledge is detailed only for western Europe and North America, though considerable scattering information has been gathered from all lands.

As our knowledge of Geology, and especially of Historical Geology, increases, the new facts brought to light suggest new ways of explaining and correlating those which we have already learned. In consequence, the older views and terminology are constantly changing, and must continue to do so for a long time to come. All knowledge that is increasing is evolving toward the truth, and what is acceptable now may be rejected with the later discovery of new facts and new interpretations.

The known geological record is at best but an imperfect chronicle of the history of the earth, and will always remain so. It abounds in breaks, marking omissions of record, some of which have been caused by non-deposition of strata, others by destruction of record through weathering away of formations, or by obscuring and altering of record through metamorphism or rock change, as explained in the first part of this treatise.

In our reading of the geologic record through the process of "trial and error," we are guided by the law of continuity or uniformity in the operations of nature: through the study of the forces at work to-day, and of their results, we learn to decipher the geologic history of our mundane sphere; and the time will come when geologists will be far more able than they are now to picture to themselves and describe to others the nature of the detailed relief of the lands, the extent and character of the oceans, and the essential life of any given time. Not even all the grander features of this history are yet known, and of the detail but little, so that many generations of workers still have a grand field of scientific endeavor before them. It is through the gathering of all of the detail that will be discerned not only the grander features in the evolution of the earth, but as well its everyday method of work and the incidental results of its physical and organic operations.

Dana has well said: "In the study of Geology, there is often an expectation to find strongly drawn lines between the eras and periods, or the corresponding subdivisions of the rocks; but geological history is like human history in this respect. Time is one in its course, and all progress one in plan."

The oceans periodically spread over the lands and the floods are as often withdrawn. Great and grand ranges of mountains have been raised many times near the borders of the continents, only to be broken up little by little and spread out as thick or thin sheets of sediments over the bottoms of the adjacent water basins. "Rocks fall to dust, and mountains melt away." Such a shifting of the materials of the high places of the lands into the lower ones or into the seas and oceans displaces an amount of water equivalent to the mass of sediments unloaded into the seas, and this tends to make the oceans overflow the lands. The great majority of these overfloodings of the oceans, however, are due to crustal movements, — depressions and elevations. The roots of former mountains remain forever where they once proudly reared their crests, but their one time grandeur can be revealed only by restoring the extent of the folds and calculating the quantity of sediments carried into the nearby areas and there laid down as formations. Why these mountains came to be, the nature of their internal rock structure, and the forces that broke them down and transported their débris to lower levels have been explained in the first part of this text-book. We are now to see the procession of these things.

The lands are slowly but continually undergoing change. Not only are the surfaces of the lands changing, but even their outlines,

and yet there has been no general interchange in position, at a given time or in the course of the ages, between the continents and the oceans. It is true, however, that the latter have often spread temporarily over the continents as more or less wide shallow seas, and also that vast areas of dry land have gone permanently into the abysses. The oceanic areas are the more permanent features of the earth's surface, and their basins have grown steadily larger at the expense of the continents. Originally the continents were vastly larger and trended east and west on either side of a mediterranean (Tethys); now they strike north and south due to vast founderings of lands into the depths of the Atlantic and Indian oceans. Australasia is but the remains of a greater Australia and southeastern China (Sino-Australia).

The geography of the earth has gone through many changes, and even during each geologic period there have been alterations of a profound kind. Great mountain ranges have been folded up in one period and eroded away in the following one; many of them have been bodily elevated more than once and as often removed into the adjacent seas. As the dynamic processes are slow in action, this observation alone indicates that the divisions of geologic time are of long duration, and that the age of the earth is very great. To restore these ancient phases of geography (= Paleogeography) is one of the most difficult of geological problems. Shore-lines are rarely indicated in the sediments, and yet the marine accumulations remain where they were originally deposited. From their nature and their organic inclusions can be deciphered the geologic and biologic phenomena of a given time, the topographic relief of the land, and whether the climate was moist or dry, warm, cool, or cold.

The chronological order is the underlying principle in all history, and in Historical Geology the orderly sequence of time is determined by the geologist through a probable succession of rock formations. The final chronological order is ascertained (1) through the actual local order in the superposed sequence of stratified rocks, and in their overlap from place to place; (2) through the degree of evolution attained by the fossils contained in the strata; (3) through the unconformities or breaks in the sequence of rock formations; and (4) through the determined order in which the igneous rocks intersect or cut one another and the stratified formations.

Just as the surface of the earth is in a continual state of slow change due to internal alterations and gravity, so in consequence must be the atmosphere, since its gases have come out of the hot interior. Even the water is born of the interior earth. When the lands are

high and the air drier than usual, then the climates are most trying upon the mountains and especially to the plants and animals living upon their flanks. Then also igneous activity is greatest, and deep-seated rock materials are being injected into the lithosphere, lavas and volcanic ashes are spread over it, and new water vapor and gases are added to the atmosphere. We are living in a time when such actions and interactions, physical and organic, are quickened and intensified, and due consideration must be given to this condition when we attempt to explain the phenomena of past geologic ages by the law of continuity or uniformity. We now know of many such crescendoes or accelerations in the physical and organic evolution of the earth. On the other hand, through vast periods of geologic time there is more or less crustal and atmospheric stability, with changes only of a mild sort. Eventually, however, the stability gives way to maximal crustal instability.

This crustal instability results in changing environments for the plants and animals, in greatest degree among the organisms of the lands, and least so in the oceanic realms. Accordingly, organic change is slowest among the organisms of the oceans, and much quickened in the life of the lands. In the later half of the earth's history, much evidence of the life of the past is preserved to us in the rock sediments, and these fossils are our main dependence in classifying and correlating the stratified rocks of a given time from place to place. During the earlier half of geologic time, the rock record is almost devoid of fossils, but by Cambrian time a fullness of marine life is at hand. Out of the marine realm came migrants upon the lands, first through choice in the fresh waters, and then through necessity in the evanescent waters and finally upon the dry lands. In the seas and oceans the organic evolution continued monotonously through the ages, but on the lands the plants and animals were in constant conflict with their variable habitats. Through ceaseless trial of effort and the weeding out of the less fit, there arose ever more perfected and higher organisms, with greater and greater mentality, to terminate finally in man. Life, once started out of water and carbon dioxide, has gone on ceaselessly, striving through force of circumstances toward better adapted mechanisms endowed with higher and higher thinking powers.

CHAPTER II

ORGANISMS, THEIR COMPOSITION, STRUCTURE, AND CLASSIFICATION

All Nature is composed of matter and energy, and if there is anything else, science has not yet been able to demonstrate it. *Matter* is the stuff of the universe perceived by our five senses, and *energy* is the perceivable or latent (locked up) activity of matter. The sum total of either remains constant. Energy may, however, pass from one form to another, and the quantity present in any given form may and does vary.

Matter, whether of the earth or of the rest of the universe, is minutely granular, complex, divisible, resistant substance. There are three states in which it occurs, the *solid*, the *liquid*, and the *gaseous*.

Matter commonly exists in more or less complex substances which can be broken up by chemical and physical means into at least eighty-six elements, including the unstable forms involved in radioactive disintegration (see page 264 of Pt. I).

Evolution of Matter. — All material nature is subject to the law of evolution or change, and in the main tends to evolve from simple to more complex conditions. The progressive change is from highly attenuated, atomically simple gases to more condensed and heating ones, and these in the course of a slow evolution change into more complex liquid and solid substances composed of one or more elements in combination.

Nature of Inorganic Matter. — Inorganic matter is lifeless material. In the crystalline form it begins in a nucleal molecule or particle; it enlarges by external addition or accretion alone, and there is hence no proper development, since the crystal is perfect, however minute; it ends in simply existing, and not in reproducing; and, being lifeless, it has no proper death or necessary dissolution. (Dana.) In other words, a crystal grows by the external addition of materials chemically the same, or of the same kind, as itself, arranged in layers, the body always retaining the same shape and constitution and never exhibiting motion, assimilation of food, internal growth, or reproduction of its own kind.

Nature of Organic Matter. — The fundamental difference between organic and inorganic matter, the quick and the dead, is that one is endowed with the quality of *irritability*, while the other is inert. In other words, the bodies composing the inorganic world are in the crystalline form, or in fragmented or altered condition; while the bodies of living matter have their substance organized into a cellular vital mechanism capable of response to external and internal agencies, and are therefore called *organisms*.

A living organism exhibits five inherent activities, — contractility, the power of movement, which is better developed in animals than in plants; irritability, the power of responding to stimulus in the wide sense, also more marked in animals; nutrition or utilization of food; respiration; and excretion, which is again greatest in animals — besides the periodic activities of growth and reproduction. Organisms are therefore "chemical machines" that have the peculiarity of preserving and reproducing themselves.

Origin of Living Matter. — Only two chemical compounds, according to Henderson, are of preëminent importance to organisms: first, *water*, and second, *carbon dioxide*. These are the common source of every one of the complicated substances which are produced by living beings. They never part company, and together with sunlight and the proper temperature, they make up the actual environment of organisms. Carbonic acid possesses the first great qualification of a food: its occurrence is universal and its mobility a maximum.

Water is the most familiar and the most important of all things. Although very mobile, it is a poor conductor of heat, and is the great stabilizer of temperature, since evaporation consumes heat and cools the surrounding atmosphere. The organism itself, Henderson says, is essentially an aqueous solution in which are spread out colloidal (glue-like) substances of vast complexity. The human body is, in fact, 71 per cent water. The body fluids of the lower forms of marine life correspond exactly with sea water in their composition, and there are strong indications that the fluids of the highest animals are really descended from sea water.

Most biologists hold that it was in the sunlighted water that life originated, and probably in the permanent oceanic basins, which may therefore be assumed to be the cradle of life. Here the conditions of life are simplest, the inorganic food materials are of nearly uniform distribution, and the energy of the sun is at its strongest and at the same time may be modified by depth of water. Marine

organisms actually float in a food medium and their environment is the most constant of all organic habitats.

For twenty centuries philosophers held that life was being constantly and spontaneously generated (*spontaneous generation*) out of inorganic matter, or that it arose out of dead animals, or developed as worms in the intestines of animals. All of the stated cases of spontaneous generation, however, have been proved to arise in invisible organic germs floating in the air and falling into water or other environment necessary to growth and development; the theory was definitely laid aside by Pasteur, who showed that sterilized cultures always became infected with life when exposed to air, and that properly filtered or sterilized air never caused infection. In the case of dead bodies giving rise to new and very different life, this is now seen to be due to insects depositing their eggs in the carcasses of animals, where they feed and develop into maggots and other larval forms. Intestinal worms arise in eggs swallowed by the host.

Cells of Organisms. — Life may be manifested in a single tiny cell or in a combination of cells (see Fig., p. 9). The simplest of plants and animals reveal their individual vital actions in a single cell. These are the *unicellular organisms*, known among plants as the *Protophyta* (means first plants), and in animals as the *Protozoa* (means first animals). The great majority of organisms, however, are composed of many cells and are therefore known as the *multicellular organisms;* here the plants are grouped under the term *Metaphyta*, and the animals under the term *Metazoa*.

The number of these cells in the higher organisms is enormous. Such a community consists "of many millions of millions of such living units far outnumbering the total population of human individuals on the earth, and this vast community of living cells which together constitute a living man or woman, are, in a state of health, so coördinated and regulated as to excel, in goodness of government and cò-adaptation to one another's wants, any social system which has ever regulated a body corporate in human history" (Moore).

Most cells are too small to be distinguished except through lenses; many single-celled animals are just visible to our unaided eyes. The most important part of the cell is a structure known as the *nucleus*, a small, granular, and solid looking body, which is thought to be the main seat of vital energy, and of the reproductive and hereditary tendencies of the species. The softer body material of the cell is known as *cytoplasm*. Under the microscope the finer structure of the plasm has a frothy or net-like appearance. This framework is known as the *linin* of the cell (see Fig., p. 9).

Evolution of the Cell. — According to the late Professor E. A. Minchin, the earliest living beings were minute, possibly ultra-microscopic corpuscles, and of the nature of chromatin only. He calls these theoretic organisms ***biococci***,

but as yet no living examples are known; they probably represent once independent and very primitive living organisms.

It is thought that the biococci gave rise to two new types of organisms: (1) one type that specialized in the vegetative mode of life, getting their subsistence out of the inorganic matter about them; and (2) another type that developed a predatory existence, feeding upon other organisms. The first type gave rise to forms like *Micrococcus;* these then evolved into the more complex bacteria and so upward into the higher assimilating plants. In the second type, the biococci evolved into the *cytode stage,* or corpuscles with chromatin grains (= chromidia) scattered in a cytoplasmic-like material having a kind of streaming movement that enabled them to engulf other organisms. The next stage was that of the *protocyte,* in which the chromatin grains or biococci were organized into a nucleus; they gave rise to the Protozoa, and out of them arose the higher animals (see Fig., p. 47).

Structure of Organisms. — In all the organisms having bodies (bodies are made up of many cells), similar types of cells are aggregated together into structures, called *tissues,* designed for serving some common office of the body, and at times two or more tissues are blended together to form what is termed an *organ* for carrying out some special task. Such are the stomach, lungs, heart, etc. There is therefore a division of labor among the cells, and an interdependence of all parts upon a wide commerce of chemical exchange (see Fig. *A*, p. 9).

Essential Differences between Plants and Animals. — The functions, cellular structure, and development in plants and animals are essentially alike, and there is no absolute distinction between them. They differ only in the detail of their functions; the two kingdoms have developed along two independent trunk lines since early in the earth's history.

Plant cells have the power of organizing inorganic matter into living plasm; animal cells subsist on organic materials alone. Further, animals have the power of purposive motion, while plants appear to be immobile. The food which most plants absorb is cruder or chemically simpler than that which animals are able to utilize, and plants do not actively pursue their food, but passively absorb it through their cell walls from their surroundings.

Cells of plants have firm, more or less thick walls, made of cellulose, which enclose the plasm with its granules of green coloring matter (chlorophyl). This stiffness of wall structure limits independence or apparent purposive movement. Plants, therefore, by means of the green coloring matter and the energy of sunlight, have the power of producing their own nutritive substances from the carbon dioxide of the air and the water, and from the salts contained in the ground. Hence they are able to exist independently, while animals are de-

pendent for their nourishment, and so for their existence, on plants. *Plants are therefore the primary magazines of food.*

Activity of Animals. — Most animals live an active life, in great part ruled by the three motives of love, hunger, and caution or fear in their widest sense; they are busy finding food, avoiding enemies, wooing mates, making homes, and tending the young. These and

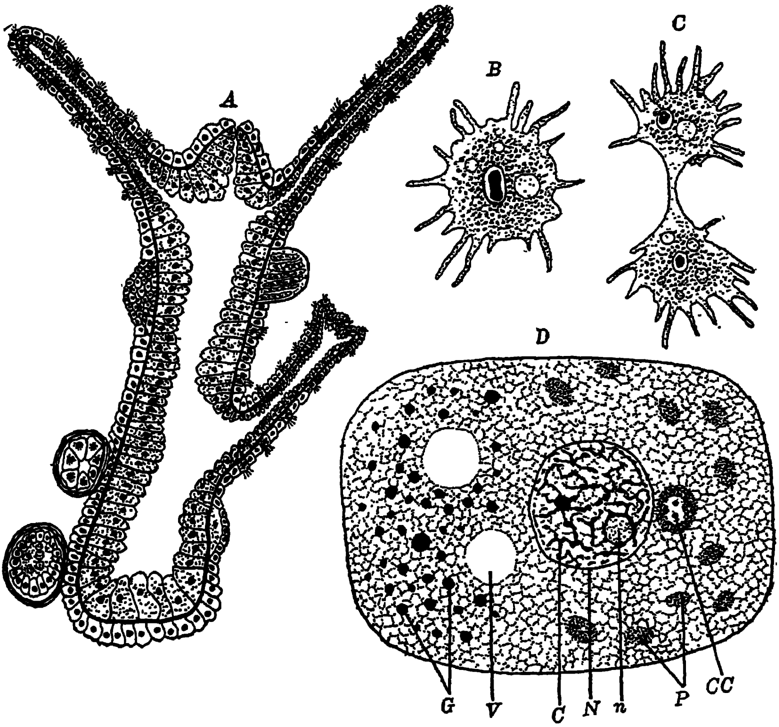

Fig. 1. — Cells and cell structure. *A*, a longitudinal section through the body and two tentacles of a fresh-water *Hydra*, to show the cell structure of a metazoan animal. Greatly magnified. *B*, a single-celled animal, *Amœba; C*, the same dividing into two individuals. Greatly magnified. *D*, diagram of cell structure and its meshwork or linin. After Wilson. Very greatly magnified. *C*, chromosomes; *CC*, centrosome; *G*, granules; *N*, nucleus; *n*, nucleolus; *P*, plastids in the cytoplasm; *V*, vacuole.

other forms of activity depend upon internal changes within the body. Thus the movements of all but the very simplest animals are due to the activity of contractile parts known as muscles, which are controlled by nervous centers and by impulse-conducting fibers, and the energy involved in these movements, and in most other vital activities, results from the oxidation or combustion of the complex carbon compounds which form a substantial part of

the various organs. Free oxygen is constantly supplied by the water or air.

The work done means expenditure of energy, and is followed by exhaustion (muscular, nervous, etc.), so that the necessity for fresh supplies of energy is obvious. Recuperation is obtained through food, but before this can restore the exhausted parts to their normal state, or keep them from becoming, in any marked degree, exhausted, it must be rendered soluble, diffused throughout the body, and so chemically altered that it is readily incorporated into the animal's substance. In other words, it has to be digested. A fresh supply of oxygen and a removal of waste are also obviously essential to continued activity. The sum of these chemical changes within the cells and the body of the organisms is known as *metabolism* (means change).

We may say, then, that there are *two master activities* in the animal body, those of muscular and those of nervous parts. To these the other internal activities are subsidiary conditions, turning food into blood and blood into tissues, and thus repairing the waste of matter and energy, keeping up the supply of oxygen, sifting out and removing waste products, and so on.

Growth and Reproduction. — Besides the more or less constantly recurrent activities or functions, there are the processes of growth and reproduction. When income exceeds expenditure in a young animal, growth goes on, and the inherited qualities of the organism are more and more perfectly developed. At the limit of growth, when the animal has reached *maturity*, it normally reproduces, that is to say, liberates either parts of itself or special germ-cells which give rise to new individuals.

The Life Cycle. — Each living plant and animal has a fairly definite duration of life. Unicellular organisms are said to be *immortal* because they grow to a given size and then divide into two individuals that continue to live and reproduce. In the higher organisms, however, with sexual reproduction, a definite span of life is peculiar to the species.

The most primitive organisms live their individual lives in a few hours, and in a general way it may be said that length of life increases with complexity of organization. The great majority of plants and animals have a span of life of but a few years. Thirty years is above the average for the vertebrates, man rarely exceeds 70 years, elephants may live a century or more, and tortoises are known to have attained to 350 years. On the other hand, among plants the forest trees attain the greatest age; the California giant

trees, the sequoias, commonly continue to live for a thousand years, and more than one tree, when felled, has showed upward of three thousand annual rings of growth.

The tiny microcosm or cell in which all life begins may pass through the life cycle before death overtakes it. Of the countless organisms born each day, but very few will complete the cycle, because the struggle for existence is especially hard on the young, and death may overtake any individual at any time. These statements, however, apply more especially to the lower types of organisms with their countless possibilities of reproduction, while in the higher life complexes the chances are better that the entities will pass through the allotted span of life.

The life cycle begins in a single cell, germ or spore, which, if of the lowest organization, divides and gives rise to a daughter cell, completing the cycle. In the more complex plants and animals, however, the cell is usually, though not always, fertilized by another cell, and then, if all goes well, this two-in-one germ (egg and sperm) evolves into the individual *embryo* that grows into *youth* and *maturity*, and then gives rise in turn to eggs or sperms, thus completing the life cycle from "egg to egg." No more wonderful microcosm exists than the fertilized cell, for it contains within itself "all the future characteristics, physical, mental, and moral, wherein the offspring resembles its parents, be they rotifers, or dinosaurs, or mice, or men!" (Lull).

Extinction of Species and Races. — Just as individuals may in old age develop senescent characters, so frequently do the races. Among these racial old age characters are the following: (1) more or less complete loss of juvenile expression and structures; (2) development of new features, as relative increase of size; (3) spinescence, or the tendency to overdevelopment of once useful or ornamental features, as spines, horns, or bodily armor; (4) physical degeneracy, as the loss of teeth or limbs, or a parasitic mode of life.

As human individuals and families die out, so do races. Extinction may be complete with the blotting out of the line, or the line may be transmuted into another family or species, and the evolution so begun may continue until wholly different looking organisms are developed. The structure of the tree is symbolic of this genesis, and as it has many branchlets on the fewer branches, and as any of these parts may give rise to other ramifications, or may die and fall away from the parent tree, so in the animal and plant trunks any of the branches may rebranch or die. In this way during the geologic ages a great many stocks have died out,

as for instance the trilobites (page 210), ammonites (page 530), dinosaurs (page 497), etc. Other stocks that are gone as such but have been transmuted into different and still living ones are the oldest known insects (Palæodictyoptera), which have given rise to the cockroaches, grasshoppers, may-flies, etc.; the toothed birds of the Mesozoic (page 582), now living in the toothless birds; the four-toed horse of early Cenozoic time (page 630), which evolved into the extinct three-toed horses whose descendants are now living in the one-toed forms, etc. Finally, some stocks appear never to die out, as the "immortal protozoans", best seen in the amœba (page 9), in the marine brachiopod *Lingula*, that has lived ever since Champlainian time, or in the lung-fishes, that have lived since the Devonian.

When races are senile, or overspecialized, or are the giants of their stocks, they are apt to disappear with the great physiographic and climatic changes that periodically appear in the history of the earth. The very ground on which some of the stocks are living at these times rises slowly many thousands of feet into a colder and thinner air. It is not necessarily the temperature, however, that kills off the organisms, but these changes unbalance the organic world of the time, and the quantity and kinds of enemies and food change, due to the harshness of the climate. In this way a new kind of struggle is set up, to which not only the senile but also many other stocks can not adapt themselves. Such stocks are then doomed and they die out completely, while the adaptable ones are transmuted into new species and among these there is set up a new struggle for the mastery of the organic world. It is the very active, alert, adaptable, and smaller forms that take the ascendency away from the rulers of the past.

Classification of Organisms

Basis of Classification. — It is instinctive with humanity to group things of a kind together; for instance, animals that feed on plants we speak of as plant-feeders (herbivorous), those which seek flesh for food we know as flesh-feeders (carnivorous). However, a natural classification is not based on mere superficial resemblances, as is sometimes thought by people who are not naturalists, and who speak of all animals that inhabit the ocean as fishes, a fact which has led to the inclusion of the whales under this term, although they are truly warm-blooded mammals and nurse their young with milk like those living on the land. Systematic biologists, that is, students of organic relationship, are careful to select, as a

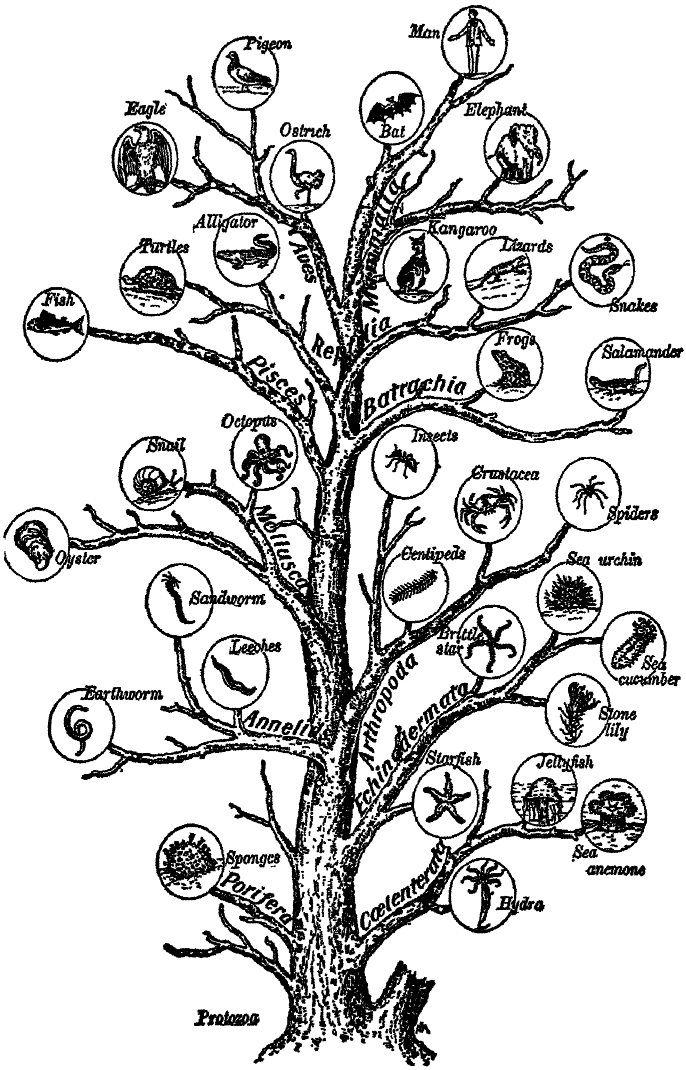

Fig. 2. — Genealogical tree of animal life, showing only the main branches (phyla). The diagram suggests the common origin of all animals in succession, with constant progressive change from the lowest (Protozoa) to more specialized types, and culminating in mammals and birds. The branching of a tree is usually taken to symbolize this interrelationship, but it should not be inferred that the origin of each phylum is in harmony with the branches as shown in this tree. Study this diagram with the one on page 19. From Gruenberg's *Elementary Biology* (Ginn and Company).

basis for grouping, such characters as have a fundamental significance leading to the discovery of natural descent, organisms with the same structure and related genealogy being classed together. This means not only that the organisms so grouped must be structurally alike at maturity, but also that they must have a very similar life development from the egg onward. The study of the stages of growth in the individual is the science of *Ontogeny*, which includes *Embryology*. This study is also applicable to the fossils and we can thus trace more or less imperfectly the history of living things back into their geologic ancestry, and the process may be continued into the most remote times. Therefore the botanist and the zoölogist must coöperate with the paleontologist in the grouping of organisms into natural classifications. In addition, the paleontologist notes the appearance of the organisms in the stratified rocks, this time-sequence being called *chronogenesis*. Therefore the named divisions in any scheme of organic classification are finally based on organic structure, ontogeny, phylogeny, and chronogenesis.

The study of living plants is the science of *Botany*, and that of fossil forms is *Paleobotany* (means botany of ancient plants). The study of living animals is the science of *Zoölogy* and that of fossil forms is *Paleozoölogy*. The study of all life, living and extinct, is called *Biology*, while that of all fossils is *Paleobiology* or *Paleontology*.

Grouping of Organisms. — All organisms are divided into the plant kingdom, or *Plantæ*, and the animal kingdom, or *Animalia*. These are the largest divisions, and while all organisms are referred to one or the other of them, in reality a sharp boundary line between plants and animals first becomes possible when they exhibit a complicated structure. This is in accordance with the theory of evolution, which holds that the higher organisms have been evolved from the lower. In common practice there is, however, no difficulty in distinguishing plants from animals.

The kingdoms of plants and animals are each again divisible like the parts of a tree, the trunk representing the kingdom, and the branches the divisions of smaller and smaller import, down to the individual leaves. The individuals that are more or less alike in their trivial characters are grouped together as *species*, for example, the domestic cats, or the domestic dogs. The different kinds of these dogs and cats, for instance, Angora cats or bulldogs, are known as *varieties*. Then all the species that have characters in common are included in a *genus* (plural genera): such are the various species

of cats (lion, tiger, puma, leopard, domestic cat), all of which belong to the genus *Felis;* or the dogs, wolves, and foxes, which are included in the genus *Canis.* The genera in turn are combined into *families,* these into *orders,* the orders into *phyla,* and the phyla into *kingdoms.* (See Fig., p. 13.)

Time Origin of the Greater Divisions. — Only about fourteen times in the history of life upon the earth have new animal phyla appeared. No new phylum has been evolved since the appearance of the fishes in the Champlainian, and no new classes since the mammals and the birds of the Triassic. It will eventually be shown that all of the phyla trace their origin back to an early period in the history of the earth. (See Fig., p. 47.)

For easier reference, the various divisions above defined may be grouped as in the following example:

Kingdom (Animalia);
  Phylum (Vertebrata, or vertebrate animals);
    Class (Mammalia, or mammals);
      Order (Carnivora, or carnivorous animals);
        Family (Felidæ, the cats);
          Genus (*Felis,* a member of the cat family);
            Species (*Felis tigris,* the tiger);
              Individual.

Names of Organisms. — It is the ambition of naturalists to describe and name all plants and animals, living and fossil, and according to the *rules of nomenclature* regulating this proceeding, each species is to have two names. The first one, the generic name, is taken from the Greek or Latin language; for instance, the genus *Elephas,* from the Greek *elephas,* elephant, and the genus *Felis* from the Latin *felis,* cat. A genus may contain but a single species or it may have several or even many, but in all cases where the species are grouped under the same generic name, it means that all have in common the structural characters on which the genus is founded. A species, like a genus, originates but once. The specific name is taken from the Latin language or is a Latinized form of a word from another tongue; for instance, the common house cat is called *Felis domestica,* the lion is *Felis leo,* the African elephant is known as *Elephas africanus,* and the Indian form as *Elephas indicus.* This double naming is called *binomial nomenclature* and was used by Linnæus in the first edition of his *Systema Naturæ* in 1735, but the method was not fully established until the tenth edition of the work (1758), the *starting point of zoölogical nomenclature.*

In America it is the custom to write the generic name with an initial capital letter and the specific and varietal names, of whatever significance, with an initial small letter. Both names are written in italics.

Definition of Species. — Lamarck correctly held (1809) that species are not fixed entities, and further that there are no sharp divisions in the organic world corresponding to the classes, orders, and genera of our biologic classifications. "A species," he wrote, "is a collection of similar individuals which are perpetuated by generation in the same condition, as long as their environment has not changed sufficiently to bring about variation in their habits, their character, and their form."

Divisions of the Plant Kingdom

Since organic evolution is a fact, it follows that there can not be a sharp distinction between plants and animals. There is, however, a marked one between all of the easily seen kinds of plants and animals, and the separation becomes difficult only among the lowest microscopic unicellular forms of life. When life began on the earth, and for a long time afterward, all forms of life were the simplest of plants, and in the course of time there gradually evolved out of them the characters which are distinctive of animals, and of the higher plants as well.

Plants and animals have had a long geologic history, and Historical Geology shows that they begin in simple forms which in the course of time become more and more complex. It was in the oceanic water that the plants had their origin, and very early in the history of the earth some of them must have become habituated to the dry lands. There is, however, no evidence of their presence during the first half of the earth's history. Once organized for a dry land existence, with roots as absorbers of water which is exhaled as vapor through the leaves (transpiration), and with breathing pores to take in the air with its food (the carbon dioxide), the main evolution of plants has been on the lands. In this way the more complex plants prepared the lands to be the future homes of the higher land-living animals. The plants which made this transmigration appear to have had a very long struggle in getting away from the water and swamps, since no land plants are known until Champlainian time. (See Fig., p. 17.)

The nine great phyla of the Plant Kingdom are the following:

(1) The marine plants that made the original passage from the sea to the swamps and then to the drier and drier lands were the

algæ or sea-weeds. They belong to the phylum *Thallophyta* or *thallus plants,* green shoots devoid of roots, stems, and leaves, and they reproduce by splitting (fission) and by unicellular spores. Berry states that thallus plants differ as much among themselves

Chronogenesis of Plants (Modified after Berry)

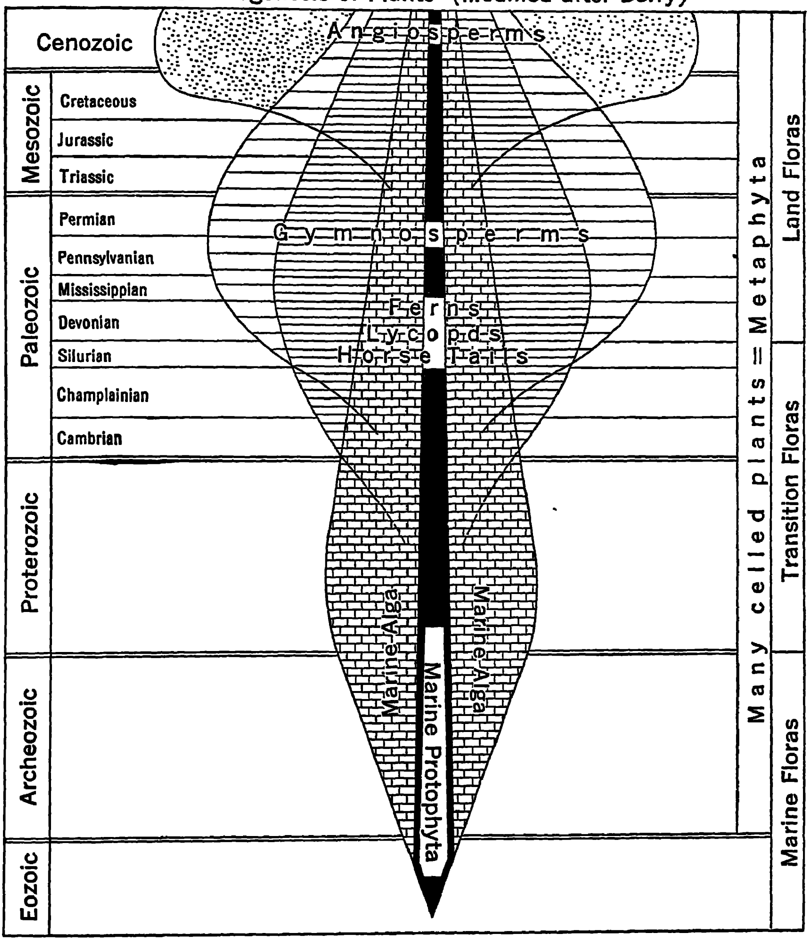

Fig. 3. — Diagram to show the geologic duration and successive dominance of the progressively more complex plant stocks; also the progressive increase in the complexity of floras with time. After Berry.

as do all the rest of the plants together. Originally all algæ were marine in habitat, but subsequently they spread into the fresh waters, and the unicellular forms over the dry lands, and even into the interior of all animals. In fact, they are everywhere, and are the cause of all organic decay, of many diseases to which plants and animals

are subject, and of the ferments in many of the human food and drink industries. The most primitive are the unicellular ones like the bacteria and molds, while the multicellular, larger, and more complex forms are the green, brown, and red algæ, the stoneworts, lichens, and mushrooms. Some of the marine algæ are of gigantic sizes, but as fossils they have little significance, being too perishable for good preservation in the strata. Some of the lime-secreting forms since ancient times have been makers of much limestone.

(2) Next higher in organization to the thallophytes are the *Bryophyta* or *moss plants*. These are almost unknown as fossils and none are older than the Age of Reptiles (Mesozoic). They have no true roots, and their transpiration tubes (vascula) are of the simplest construction.

(3) The *fern plants* are known to all and are included in the phylum *Pteridophyta*. They have been in the world since at least Devonian time, and in the Pennsylvanian there were tree-ferns 50 feet tall. These plants have stems, leaves, spores, and roots, and true woody or vascular structures.

(4) Next higher in organization are the *rushes* or horsetails of the phylum *Arthrophyta*. These are herbaceous and tree-like spore-bearing plants, in which the stems are ribbed and articulate at the nodes where the whorls of leaves are situated. This phylum includes some of the oldest known land-living plants, and attained its maximum differentiation in the Paleozoic.

(5) The highest of spore-bearing plants, widely known as *lycopods*, are but illy represented in the living world by the club mosses or crowfoot and the ground pines. They are of the phylum *Lepidophyta*, dominant in the land floras of later Paleozoic times and, together with the arthrophytes, making up most of the coal accumulations of that part of the earth's history (see Fig., p. 17).

(6) The most primitive seed plants are the *seed-ferns* of the phylum *Pteridospermophyta*. They look very much like ferns, and in fact have much the same anatomical features, but instead of spores have well developed seeds. The phylum includes " a plexus of synthetic seed plants." Arising out of the ferns and appearing in the Devonian, the whole stock vanished with the Permian.

The seed-ferns (6), cycads (7), and conifers (8) in the older classifications were embraced under the term *Gymnosperms*, and are so included in Fig., p. 17.

(7) The *cycads* or sago palms of the warm climates of to-day are of the phylum *Cycadophyta*, but a host of very diverse forms lived

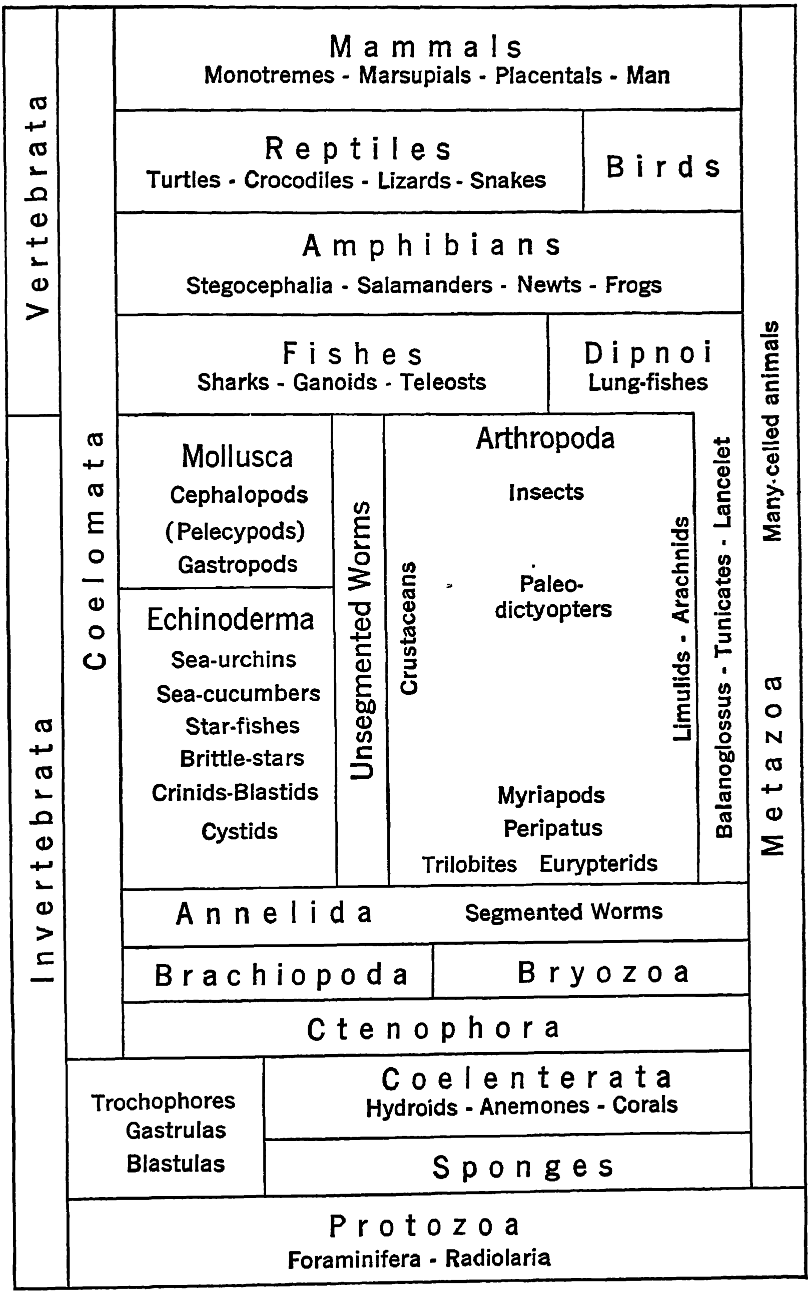

Fig. 4. — Diagram to show the interrelationship of animals, beginning with the lowest type at the bottom and closing with the highest at the top. Study this diagram with the one on page 13.

all through the Mesozoic and particularly during the earlier half. They arose out of the seed-ferns.

(8) Pines, redwoods, sequoias, junipers, and cypresses are known to all. They are of the phylum *Coniferophyta* or cone-bearing trees, so called because so many of them have their seeds in cones. They are also known as *Gymnosperms* and *evergreens*. These seed-bearing and decidedly woody plants made up the greater part of the ancient forests. Their flowers were fructified by the wind blowing pollen upon them, and never through the agency of insects. The cone trees arose long before insects had appeared, in fact, they developed before Devonian times out of the " plexus that gave rise to the seed ferns " (Berry).

(9) The highest of all plants are the *hardwood trees* and our beautiful *flowering plants* (phylum *Angiospermophyta*), of which more than 100,000 living kinds have been described. They appear in the Jurassic (earliest in the southern hemisphere) and are thought to have arisen out of the preceding phylum. All have closed ovaries, a condition seen in no other plants. All other seed-bearing plants (phyla 6, 7, and 8) are said to have open or naked ovaries, and they are sometimes combined into a single phylum, called *Gymnospermæ*.

Divisions of the Animal Kingdom

The animal kingdom is divided into two subkingdoms, *Protozoa* and *Metazoa*. In the former the individual or unit animal consists of a single cell, that may lead a free life independent of its associates, or with them may combine into colonies. In the colonial form, however, each cell is a complete individual and there is as a rule no division of labor among the members of the colony. In the Metazoa, or higher animals, as they are usually called, the cells are grouped into tissues and organs, and there is always a division of labor among them. In other words, the Protozoa are usually very simple microscopic animals, almost unknown except to naturalists, while the Metazoa are multicellular animals, varying greatly in size and of different degrees of complexity. (See Fig., p. 13.)

The animal kingdom is divided into at least fourteen phyla, and nine of these have an abundance of fossil representatives. These latter are as follows:

(1) *Protozoa,* above defined as the single-celled animals. Includes Foraminifera and Radiolaria.

(2) *Porifera* or *sponges.*

(3) *Cœlenterata,* or animals with a very simple, sac-like, digestive cavity, having but one opening, the mouth. The stony corals are

the best known representatives, the jelly-fish the most watery, and the flower-like anemones the most beautiful.

(4) *Echinoderma*, or *spiny-skinned animals*, such as starfishes, brittle-stars, sea-urchins, sea-cucumbers, and feather-stars or stone-lilies. They were wonderfully varied and prolific in the Paleozoic.

(5) *Bryozoa*, minute, *moss-like animals* that at times are great limestone makers. Often the Bryozoa are combined with the Brachiopoda in the phylum Molluscoidea, but we prefer to regard both as distinct phyla.

(6) *Brachiopoda* or *lamp-shells*, animals with two valves, but wholly unrelated to the bivalved molluscs.

(7) *Mollusca* or *shelled animals*, like the clams and oysters, the snails and drills, the pearly nautilus and ammonites, and the octopus.

(8) *Arthropoda*, or *jointed-limbed invertebrates*, having more diversity of form than all the other phyla together. Here belong the shrimps, lobsters, and crabs, the trilobites and horseshoe-crabs, and the endless variety of insects, spiders, and thousand-legs or centipedes.

(9) *Vertebrata*, the highest animals, having an internal bony skeleton, the diagnostic part of which is the vertebral column or back-bone. Here belong the fishes and eels, the toads, frogs, and newts or batrachians, the reptiles, the birds, and the mammals.

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CHAPTER III

FOSSILS, THE GEOLOGIST'S TIME MARKERS

Living plants and animals constitute the present organic world, while fossils are the remains of organisms that have lived in the geologic past. Fossil-bearing strata are the graveyards of the buried past, of the lost races connecting the past with the present. "The dust we tread upon was once alive" (Byron). The New York State Geologists, when they entered upon their work in 1838, found fossils "in the stone fences and farm foundations; they lay loose along the streams and on the shores of the Finger Lakes; and they protruded from the rocks on the edges of the cliffs. So ubiquitous were they that the Seneca Indians used the fossil cup-corals for pipes, strung together the joints of crinoid stems into necklaces, and buried brachiopod shells along with axes and spear points in the graves of their braves" (Clarke).

Fossils may occur in any sedimentary rock of the low land near the sea or far inland, or even in the highest mountain ranges. They indicate not only the kinds of animals which have lived, but a great deal about the nature of their home surroundings as well. For example: the remains of a marine animal, such as an oyster, found naturally entombed in strata anywhere on the present land indicate that where the relic now occurs the sea existed at the time when the organism was living.

Ancient Views about Fossils. — The fact that fossils resembling in every way the shells of marine animals are found far inland has long perplexed mankind. Some of the Greeks in the third and fourth centuries before Christ explained them as ineffectual attempts at creation by a *plastic force* inherent in the earth. This poetic interpretation arose again and again in the subsequent centuries, and the "controversy about fossils" was particularly acute after the fifteenth century. These occurrences were then regarded by many as mere mineral concretions and described as *lusus naturæ*, freaks of nature, while others said that these "figured" or "formed" stones were made in the soil of the earth under the influence of the stars. Still others correctly held that fossils could only have belonged to once living plants and animals,

but attributed their presence in the rocks to the Deluge, believing that not more than 6000 years had elapsed since the time of the Creation and that the Flood had been universal, destroying all life and spreading its remains far and wide over the lands. "They had no conception of the physical impossibility of accumulating all the fossiliferous formations of the earth's crust within the space of one hundred and fifty days during which 'the waters prevailed upon the earth, and all the high hills that were under the whole heaven were covered,'" as Sir Archibald Geikie has said. Thus arose the "diluvial theory" and with it a bitter controversy that only ceased late in the nineteenth century.

In the Mediterranean countries, however, the younger geological formations "underlie many of the plains and rise high along the flanks of the hills. In these deposits, shells and other remains of sea-creatures have been preserved in such vast numbers as could not fail to arrest attention even in the infancy of mankind. Since the organisms are obviously like those still living in the neighboring sea, the inference could readily be drawn that the sea had once covered the tracts of land where these remains had been left. This conclusion was reached by some of the earliest Greek philosophers [especially Xenophanes, 576–480 B.C.], and there can be little doubt that it led to those wide views of the vicissitudes of Nature which were adopted in later centuries by their successors." (Geikie.) Thus arose the theory of "cataclysms and re-creations," one that was laid aside only in the past century for the theory of evolution, which teaches that life, once originated, has continued uninterrupted to the present.

Transition of Present Life into Fossil Forms. — The easy transition between the living marine molluscs (shell-fish) and their geologic ancestors is best understood by the following examples. The Pleistocene formation is the youngest of geologic deposits and in it, at a given locality, all of the species may be of still living forms, while at another place where the deposits are older, as many as 25 per cent may be of extinct species. In the still older Pliocene, less than half of the forms are of living kinds, and in the next lower formation, the Miocene, only from 20 to 40 per cent are of recent species. Finally, in the oldest of Cenozoic formations, the Eocene, there are rarely more than 5 per cent of living shelled animals found. In other words, the present life shades gradually into that of the geologic past, this transition being most gentle among the marine invertebrates, while but few of the living species of land-inhabiting vertebrates are known in the geologic formations. This is because

evolution has gone on more slowly among the marine invertebrates and the land plants, and most rapidly among the land mammals.

What Fossils Teach

Fossils are not freaks of nature, nor are they merely chance relics of things once alive, but they are the very important geologic records from which has been unraveled so much about the history of the earth. These records reveal (1) the course organic evolution has taken, along with the geographic distribution of plants and animals; (2) the sequence of geologic time or chronology; and (3) the nature of the environment of the fossils, whether they lived in marine or fresh waters or on the dry land, and something about the depth and temperature of the seas and the climates of the lands.

As the first-mentioned value is of most importance in pure Paleontology and general Biology, it need not be treated in detail in this book. The chronogenetic value of fossils is, however, of great import in Historical Geology and needs, therefore, to be studied with some care. All life has constantly changed, not only as to specific form but as a rule in definite directions from the simpler to the more complex types of structures, although often also in the reverse manner. For these reasons, fossils are of the greatest value in determining the past history of the earth.

The *time value of fossils* was first discovered by William Smith and published between 1816 and 1820. He said that " each stratum contained organized fossils peculiar to itself ", but this law considers only the significance of fossils as " medals of creation ", and as " the classified signs by which geological formations may be recognized. This is the scope of the older paleontology. The higher or comparative paleontology, as set forth by Cuvier (1800–1832), Deshayes, Lyell, and Lonsdale, considers the relationship which fossils bear to each other, to those which preceded them, and to their successors. It deals with the history of organisms, and therefore is able to find in fossils themselves evidence of the order of sequence of the rocks containing them" (H. S. Williams).

Habitats. — Every species of the plant and animal kingdoms has a given home or environment, known as its habitat, which may be dry land, rivers and lakes, or seas and oceans. Moreover, temperature varies between the poles and equator, and therefore organisms are cold, temperate, or tropical in their adaptations. All of these differences in habitat are reflected in the fossils, which are therefore guides to the past climates and kinds of environments.

Of course, dry land organisms may be washed into water habitats, but when this occurs, they will show this accidental mixing, and the further fact that the land was not far away from the place of entombment.

Guide Fossils. — As all organic races, like individuals, have a span of life, and usually a short one geologically speaking, it follows that, since species and genera are constantly changing, they are more or less indices or *guides* to the time of their existence. Some fossils are better guides than others, and can be used accurately in correlating the strata of a given age from place to place or even from continent to continent.

Facies Fossils. — It has been pointed out that since all present and past life is adapted to a particular environment, it follows that the kinds habituated to marine or fresh waters, to lands, or to cold, temperate, or warm climates, will show even among the fossils their former habitats. In addition to this, marine organisms living on mud bottoms will usually be different from those habituated to sand or lime bottoms. The freely swimming or floating forms, however, may be found in all kinds of sedimentary deposits, since at death they fall on any kind of a substratum. These different habitats are said to impress their *facies* (sand, mud, or lime environment) on the organisms of a given time and place. It is true that some species can live on any kind of bottom, but as a rule each kind is addicted to, and spends its life on, a distinct type of marine bottom. Bivalves and horseshoe-crabs prefer mud or sand, while crabs live on any kind of bottom, and at night will even come ashore in search of food.

Evolution and Superposition. — To ascertain the course evolution has taken, the fossils must also be studied in the order of their appearance in any given series of rocks, and this is done by noting their occurrence in the strata. Those in the lower rocks naturally must be older than those in the higher or superposed strata. The order of superposition is usually determined in regions where the earth's crust has not been disturbed, for here bed upon bed of rock occurs as laid down by the waters (see Frontispiece); but where the strata are faulted or deformed into mountains the natural order of stratigraphic sequence is at times very difficult to ascertain. However, after one hundred years of endeavor a great deal of knowledge has been worked out as to the evolutionary sequence of organisms, and this knowledge, as determined in many countries, can now be relied upon to fix in turn the stratigraphic sequence.

How Fossils are Preserved

Fossils always occur in sedimentary or stratified rocks that have been laid down in bodies of water, or on the lands through the action of the winds. Another type of sedimentary strata having the possibility of fossils consists of volcanic ashes, which at times of outburst are shot high into the atmosphere and then carried by the winds for shorter or longer distances over the lands or seas, burying all living things. In this way the Roman summer resort, Pompeii, was buried by ashes from the volcano Vesuvius in the year 79 A.D. To-day in digging out the city some of the victims are found in the form of molds, so that when these hollow spaces

Fig. 5. — A tangle of fossil moss-animals (Bryozoa). Originally carbonate of lime, now replaced by silica, and etched out of limestone. A true pseudomorph without the original microstructure.

in the fine ashes are filled with plaster of paris, good casts of the people and animals as they appeared in the flesh are obtained; such may be seen in the National Museum at Naples. The bones of human victims are also occasionally found under a thin flow of lava, as is the case at Pedregal de San Angel, near Mexico City. However, fossils are not often found under or in the basal sheet of lavas and it may therefore be said that in general they do not occur in igneous rocks.

Any dead organism exposed to a temperature above the freezing point of water is, as a rule, at once attacked by the ubiquitous microscopic fungi and bacteria of the plant kingdom, and by the

small and large scavenging animals, and soon vanishes without leaving a trace of its former existence. In this process the oxygen of the atmosphere also assists, and the same is true for organisms under water, only in the latter case complete destruction is slower. The dissolving effects of circulating waters in most cases complete the destruction of even the harder skeletal parts. In other words, the individuals of entire floras and faunas are seen at the present time to vanish under the influence of other living things, and of the atmosphere and hydrosphere. It is probable that more than 99 per cent of all life has thus been removed. Every organic trace may be oxidized and dissolved into the elements from which it came —

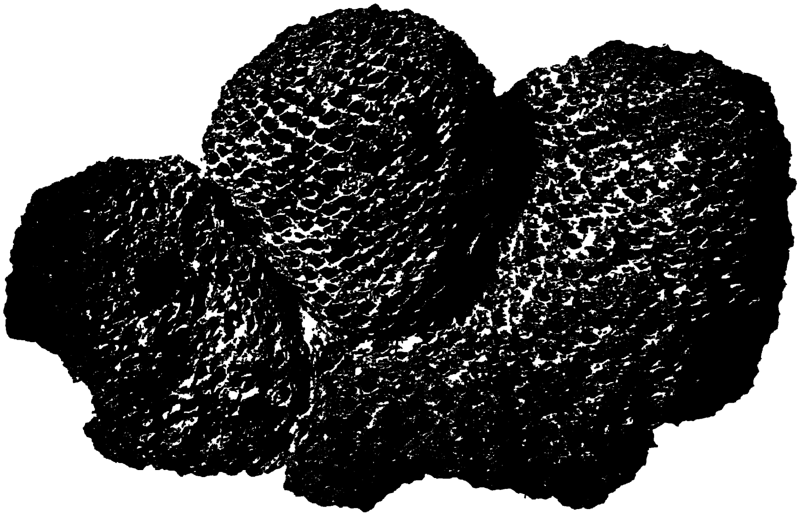

Fig. 6. — A fossil cycad, or plant distantly related to palms. The original wood is replaced by silica, yet the original microstructure is preserved. See Fig., p. 29.

into the air, water, and the dust of the earth. Therefore, if an organism is to be preserved as a fossil it must be covered quickly by sediment, and even then only a mold of the exterior form may remain. Complete destruction is the rule among all organisms having soft bodies devoid of hard skeletal parts, and it is the exception among such to leave behind even a mold of their bodily form. Where there is a skeleton, either external, as shells, or internal, as the bones of vertebrates, it again depends upon the character of these structures, upon the character of the sediment, and finally upon the chemical content of the waters in the rocks whether these parts are to be preserved or only to give evidence of their existence in the condition of molds.

Deformed Fossils. — Most sediments undergo consolidation during their accumulation, due to superposed load, and especially to the water being squeezed out, permitting closer compacting of the granular material. Compacting is especially great for the mudstones, and the organisms included in them have undergone much crushing and more or less distortion. When strata are folded into mountain ranges, they are further subjected to enormous pressures, and in consequence the rocks are either squeezed together or stretched. This condition is again especially true of the mudstones.

On the other hand, strata that have been replete with fossils may lose every recognizable trace of them by being subjected to the heat of large igneous intrusions, or more commonly by suffering great pressures during times of crustal deformation resulting in ranges of mountains, as described in Chapter XIII of Pt. I of this text-book. These are the metamorphosed rocks, and whether recognizable fossils are present in them or not depends upon the character of the sediments of which they are composed and the degree of alteration which they have undergone.

Nature of Preservable Parts in Organisms. — The skeletons of plants are very rarely made of *silica*, this condition being found only among the single-celled and microscopic diatoms. These are so small that in a cubic inch of tripoli there are 41,000,000,000. (See Fig., p. 69.) Among the animals, silica is also used sparingly, and is almost wholly restricted to those forms living in the sea. The microscopic diatoms and radiolarians (see Fig., p. 70) use it freely, and among the sponges probably somewhat less than one half have a siliceous skeleton. In these sponges the silica of the skeleton is in the colloidal form (not crystalline but like opal) and is therefore easily destroyed during the process of organic decay; hence the glass-sponges (see Fig., p. 199) are rarely preserved as fossils and are common only in Mesozoic strata. Among the diatoms and radiolarians, however, the silica occurs in the insoluble form and is very rarely destroyed at the time of deposition or afterwards.

Calcium carbonate is used liberally by many types of invertebrates but in plants it is utilized freely only among the marine and fresh-water calcareous sea-weeds. Here the sulphate of lime of the waters is converted by the organisms into the carbonate of lime of their skeletal structures, bound together by an organic base. This secretion is known as *conchin* and crystallizes in two mineral forms, as *aragonite* (harder and heavier, crystallizing in the rhombic system, and easily soluble) and *calcite* (crystallizing in the hexagonal system). Sometimes a structure consists entirely of

aragonite or entirely of calcite, but usually both forms exist in the same individual, as for instance among the Mollusca, where the inner mother-of-pearl layers are of aragonite and the outer porcelanous layers are of calcite. In other cases the calcite predominates, as in the oysters. At times the granules or fibers of mineral matter in the shells are associations of aragonite and calcite. It is very important to know this, because structures in the form of calcite, or in which this mineral dominates, are very apt to be preserved as secreted by the organisms, whereas such parts, when secreted as aragonite, are very rapidly dissolved away during decomposition or are replaced by other minerals through the agency of the percolating

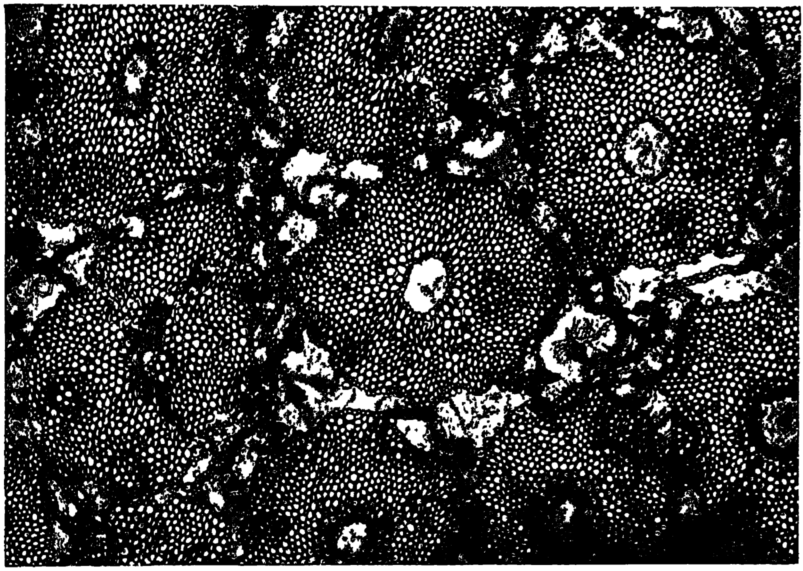

Fig. 7. — The microstructure of a fossil cycad showing the cells arranged into tissues. x about 20. See Fig., p. 27.

waters in the strata. In the Paleozoic rocks it is almost the rule for the aragonite structures to be gone, this being especially true among the Mollusca, but in the Mesozoic and Cenozoic the mother-of-pearl layers are much more commonly preserved. Just why this is so is not yet determined. The internal skeletons of vertebrates, the bones, are composed largely of phosphate of lime bound together by an organic compound (collagen).

Other much thinner, and usually somewhat flexible skeletal structures consist of a compound of the nitrogenous substances of the ammonia group and a carbohydrate, known as *chitin*. This material

has great resistance to chemical agents and is therefore hard to destroy. Among fossils it is often preserved in one form or another. Chitin makes the external skeleton of many kinds of invertebrates, for example, the arthropods (horseshoe-crabs, trilobites, insects), and to it are often added lime salts. A similar substance is *spongin*, which composes the fibers in bath sponges; this is rarely preserved among the fossil forms. *Keratin* contains sulphur in addition to nitrogen, and is but very rarely preserved among the fossils; it makes up the hairs, nails, and horns of mammals, the feathers of birds, and the scales of fishes.

Preservation of Soft Parts. — It has been stated above that the soft parts of animals are only exceptionally preserved. The most remarkable preservation of entire animals, however, is the case of those buried in the tundras (frozen ground, mainly ice) of northern Siberia, where great woolly elephants (*Elephas primigenius*) have been kept intact in natural cold storage. How long these carcasses have been entombed in the tundras it is difficult to say, certainly thousands of years, and yet the flesh when exposed on the melting of the ice is greedily devoured by the dogs of the Siberian peoples. The skeleton of one of these mammoths, found at the mouth of the Lena River, and another from Beresovka, with the mounted skin and skeleton and all of the internal organs kept in alcohol, are shown in the Natural History Museum, Petrograd, Russia. A hairy rhinoceros (*Rhinoceros tichorhinus*) has been found in Siberia preserved in the same way, and similar but far less perfect preserval occurs in the frozen grounds of northwestern Alaska. Finally, large parts of the skin of a rhinoceros have been found well preserved in the petroleum seepages of Galicia.

Molds of the entire exterior of organisms are often found, even of such extraordinarily soft-bodied animals as the jelly-fishes or medusæ, in which the organic substance is at least 95 per cent water. The most wonderful examples of such come from the Jurassic limestones of Solenhofen, Germany.

Color Preservation. — It is exceedingly rare to find among the fossils a trace of their former color. When they are preserved in light-colored shaly limestones, the former color pattern may be present in dark bands, such being known as far back as the Champlainian. The mother-of-pearl color, or nacre, is, however, often preserved and especially well in limy shales impregnated with petroleum, but this color is due to the play of light in the prismatic or aragonitic portions of the shells, and not to a pigment in the material.

How Fossils Occur

Fossils occur in any one of seven different natural conditions, three of which relate to the substance left by the organisms, three to their form, and one to both. (1) The great majority of fossil specimens preserve more or less of the original hard or mineral substance of the individual plant or animal, and to this may have been added, in the organic interstices, during the process of mineralization, more or less of other mineral substance, forming *permineralized fossils*. (2) When the original mineral matter is exchanged

for another and usually a dissimilar mineral, with the substitute preserving the original microscopic structure of the organism, the process of substitution is called *histometabasis* (two Greek words that mean *tissue exchange*) (Fig., p. 29). In this condition the woody parts of plants are often preserved and for study purposes are as good as the similar parts of living plants. (3) Plants may be wholly *carbonized* (coal), with the original organic structure more or less completely destroyed during the process. Such fossils have little paleontologic importance, but are of great economic value and are often used as datum planes in Stratigraphy and Structural Geology. The form of organisms with the original substance absent may occur in the rocks as (4) *molds*, (5) *imprints*, and (6) *natural casts* (Fig., below). There is no marked difference between molds and imprints other than that the latter term is applied to

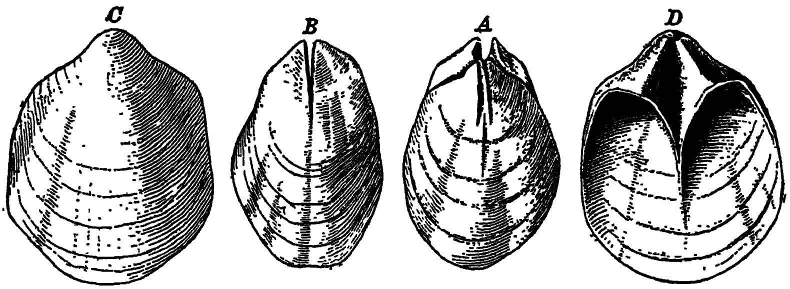

Fig. 8. — Four views of a brachiopod, to illustrate molds and casts. *A*, a natural mold of the interior of the joined shells as seen from the dorsal side. *B*, the same as seen from the ventral side. *C*, an artificial cast of the ventral exterior taken from a mold not illustrated. *D*, an artificial cast of the ventral interior taken from *B*.

impressions of thin substances, as leaves, etc. Natural casts are the counterparts of organisms made by filling the molds of fossils with an uncrystallized substitute; (7) when the replacing material is a crystallized mineral, as calcite, pyrite, and more commonly silica in the form of chalcedony, the replacement is called a *pseudomorph* (from two Greek words that mean *false form*) (Fig., p. 26, also study Fig., p. 32).

Fossil wood occurs in almost incredible quantity to the north and the south of the Colorado River. Here and elsewhere the siliceous logs lie prostrate in continental deposits of stream origin, or stand upright in volcanic ash. The petrifying agent during the process of histometabasis appears to have been the periodic alkaline waters of semiarid or arid climates, holding in solution silica that percolated through the unconsolidated sands or ash while accumulating. The silica takes the place of the woody tissue, molecule by molecule, and in most

cases preserves to a wonderful extent the microstructure of the plants (Figs., pp. 27, 29). Logs entombed in continental deposits of pluvial climates are dissolved away and occur as casts or coal. The woody tissue may also be replaced by calcite, but here the replacement appears to have taken place under a permanent cover of water, and also shortly after entombment, as in the "coal balls." Most of these rare occurrences are found in fresh-water swamp deposits, and it is a question if such replacement ever takes place in marine strata.

Tracks of animals crawling around on the muddy floors beneath bodies of water, and especially in the sea, are very commonly preserved. Land animals also often leave their tracks in the geologic record, but these, when of vertebrates, in most cases occur in red clays or sands laid down in deserts or at least in arid regions. Reptile tracks are often seen in the Carboniferous (Mauch Chunk) and are especially abundant in the Triassic.

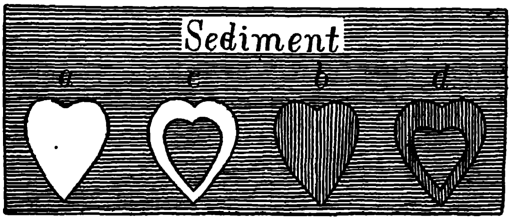

Fig. 9. — Diagram to illustrate molds and casts. The horizontal lines represent sediment, and the vertical ones the subsequent filling. *A*, the natural external mold of a bivalve with the shells removed by solvent waters. *C*, the same shell, but having the original cavity filled with sediment = natural internal mold. *B* and *D*, the molds filled by solvent waters with foreign materials = a cast and a pseudomorph.

Geologic Change in Organisms. — In Cenozoic deposits it is the rule to find the marine shells almost unchanged by the addition of mineral matter, and in general it may be added that the older the organisms are geologically, the more mineralized they are apt to be. Probably 50 per cent of all fossils still remain in their original calcareous condition or are but slightly permineralized. This mineralization may have taken place through the waters percolating in the rocks at any time after the entombment of the fossils or during the time of weathering of the formations, but it is more apt to have occurred during the time of burial, when the ground waters of the sea-floor were charged with carbonic and other acids derived from organic decomposition. For these reasons, the fossil skeletons of organisms occur in all conditions from the unchanged to complete pseudomorphs in calcite, dolomite, silica, iron pyrite, or even lead, zinc, etc.

Again, the percolating land waters or the ground waters of the sea may have dissolving powers only, and remove all of the organic shells; in this case their former presence is indicated by cavities in the rocks, the molds of organisms, more commonly seen in dolomites and sandstones. These molds are often so wonderfully sharp that the finest artificial casts or squeezes can be made from them. On the other hand, it often occurs that molds, and especially those in dolomites, are covered with a lining of crystallized mineral matter, in which case the fossils are nearly always valueless. Even though molds are bulky to collect, nevertheless they should be gathered, and the casts on the inside of them, the filling of the interior cavities of the organisms, should be secured as well. Imprints are more commonly seen in the shales and are the impressions in mud of the exterior parts of plants and animals.

Where Fossils Occur

Fossils are to be especially looked for in the evenly bedded strata of marine origin that are more or less calcareous or magnesian, and least of all in the red shales and sandstones. In nearly all of the red beds other than red limestones it is the exception to find fossil remains, because the plants and animals have been oxidized and dissipated during the process of subaërial sedimentation. It is therefore the green, blue, gray, black, and subsequently oxidized yellow beds that are apt to hold fossils. However, the red shales and sandstones may also have such fossils as the foot imprints or trails of animals, very rarely the bones of vertebrates, and still less often the imprints of plants or chalcedonized woods. In fresh-water deposits fossils are usually very scarce, but subsequent to the Silurian such beds may have plant and vertebrate remains.

The accident of burial has much to do with the decided differences between the kinds of organic records, for an animal living in the shallow sea and especially in or on the sea-floor is in the most favorable place for entombment, while only those animals of the land can leave fossils which live in, or whose bodies are swept into, some area where sediment is accumulating; the most abundant land fossils being remains of those animals which dwell on delta plains or partly within the rivers.

Of all stratified rocks, shales make up 80 per cent, sandstones about 15 per cent, and limestones 5 per cent (see Pt. I, p. 281). It is in the limestones, "the preserving salt of the geological world" (Hugh Miller), that fossils are nearly always present in abundance, but this does not mean that for every foot of limestone, nine of the

shales and sandstones are barren of organisms. Carbonate of lime is widely disseminated throughout the strata, and in all the calcareous shales there are apt to be fine fossils that will weather out free; even the calcareous sandstones usually have organisms in some abundance. Further, the thick green and blue shale formations often have thin beds of impure limestone or sandstone and in these bands fossils should be looked for.

Conglomerates may abound in fossils, but here especial care must be exercised in keeping apart the specimens of each pebble, as these may be of very different ages. The fossils of the matrix also must not be mixed with those of the pebbles, for otherwise an impossible chronogenetic association will result. On the other hand, the breccias and intraformational conglomerates have the same species as the binding matrix, because all were formed at the same time.

How Fossils Are Collected. — In looking for fossils there should be no haste, as the work of collecting is always a slow process. It seems to be a common opinion that paleontologists " scent " the presence of fossils, a conclusion that is wholly erroneous, for they are often discovered only after patient hunting.

On any exposure of stratified rocks fossils may occur, and therefore the surface should be scanned for loose specimens. These free fossils are the most desirable, because they require the least labor in cleaning, and, further, they show all parts of the individual. All residual red clays should be searched, as these are often replete with fine free specimens, usually preserved in silica as pseudomorphs.

When loose fossils are found, these should be traced to the bed from which they come and the occurrence of others still in place noted. Naturally the best places to find fossils are in the hard protruding ledges of limestone, and all such should be broken here and there with the hammer. Sometimes a thin zone will be one mass of fossils, and when weathering has loosened them so that they will fall out freely when hit by the hammer, the easiest way to collect such is to take away a lump from 6 inches to a foot across. In this connection it should be added that weathered rock yields fossils far more easily than that not so affected.

Fossils of a siliceous nature and partially weathered out of limestone should be gathered in bulk, to be treated in the laboratory with dilute hydrochloric acid (Fig., p. 26). Material which will bear this treatment is readily tested in the field with a pocket knife; if the blade does not scratch the fossil, but leaves a black mark, it will be well to make the experiment. Of course where the fossils are in cherts or are more or less surrounded with amorphous silica, nothing can be done to free them.

The field geologist in collecting fossils for study by the paleontologist will do well to remember that the value of the work of the latter depends largely on the number of specimens he can study, and therefore as much material as circumstances permit should be

gathered. It is not so much a quantity of *specimens*, however, as it is of *species* that a paleontologist desires, because it is known that different forms have very different chronogenetic values.

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CHAPTER IV

EVOLUTION, THE CONSTANT CHANGE OF LIVING THINGS

Man lives and has his well being among plants and animals, but of the extraordinary abundance and variety of this life he generally has but the slightest conception. All of it is well ordered and subject to the laws of nature. In fact, the universe is *cosmos*, not chaos, and all inorganic and organic nature is subject to unaltering natural laws. But this does not mean that all of nature's parts are fixed and unchangeable, rather "nothing is constant but change." In other words, all Nature is in ceaseless change subject to natural laws.

Prodigality of Organic Nature

Truly, the prodigality of organic nature is beyond comprehension, and equally so is the wastage of individuals. Nothing is more obvious in Historical Geology than the many failures in the long procession of life, and yet "nothing is more clear in Paleontology than Nature's set purposes." What these purposes are is not known, but the order, sequence, and meaning of life — the evolution of organisms — naturalists are constantly trying to unravel.

The upper sunlit waters of the oceans abound in microscopic life, chiefly of plants. They are the primary food supply of all animals and their abundance is attested at night by the wonderful glow of the seas; at times of greatest abundance there are millions of individuals in each quart of water. Nor is microscopic life less abundant on the bottoms of the shallow seas, and shell banks have countless individuals upon which countless other animals are feeding. McAtee says that an acre of woodland about Washington, D. C., has in the upper inch of soil not fewer than two million plants and more than one million animals, while the meadows have about ten and sixteen times as many more, respectively. This is in the temperate climate where *variety* is far less than in the tropics. On the swampy forest surface beside the Amazon River, Beebe found of easily seeable animals about a thousand within an area of 4 square feet, which means more than six billion individuals in a mile of the jungle floor.

Aristotle (384–322 B.C.) is said to have described about 500 different kinds of organisms in his *History of Animals*, and it is probable that he knew more forms than any other naturalist up to a few centuries ago. In 1758 Linnæus noted in his famous work, *Systema Naturæ*, 4236 species, and now naturalists estimate the described forms as numbering upward of 600,000. Of this total about one half are insects, and Howard estimates that when all the insects are described the number will be nearer 3,500,000. Of living plants, on the other hand, fully 200,000 kinds are described and it is thought that this total will easily rise to above 300,000.

The *number of known fossil forms* is much smaller because of the great imperfection of the geologic record. The degree of this incompleteness can be brought out with striking effect by the statement that upward of 13,000 species of living butterflies have been described, while of fossil forms only 22 are known, and one half of these are from a single locality, Florissant, Colorado. In 1820 there were known 127 species of fossil plants and 2100 of fossil animals. An estimate brought up to date places the number at about 100,000 species, and when this sum is contrasted with that of living described forms, the ratio is as 1 to 5. This, however, is very far from the exact truth, for we are contrasting all of geologic time with the very short present. If, then, we wish to determine the number of kinds of animals that have lived in the geologic past, we must multiply the 600,000 described species of living forms by at least 200 geologic units, as so far determined for North America, each one of which is at least the equivalent of Recent time; and even then the figures are far below the actual number of species that have lived. Though it is true that life became progressively more varied with time, still the comparison made is only with the described species and not with the estimated number of kinds that probably are living at present. Therefore it seems safe to state that for every 100,000 kinds of fossil animals that lived we probably know only about 1000. However, we must emphasize the fact once more that "not one-fifteenth part of the exposed rocks of the earth has yet been closely scrutinized for these life records" (Clarke). "The whole geological record is only the skimmings of the pot of life," says Huxley; and yet it does give a vivid glimpse of the extraordinary array of organisms which peopled the world of the past.

Variability of Individuals and Species. — All observant and thinking persons know that a young horse is always a horse and never a zebra or an ass. In other words, animals during their growth do not change into other species, and even though they alter their

appearance greatly from birth to maturity, these alterations are characteristic of the form observed and of no other. Therefore it is said that each species " breeds true " in its specific characters, and this relation between parent and offspring is called *heredity*. A close analysis of this resemblance, however, shows that it is never an exact one, for each individual of every species has its own peculiarities. Long ago the Italian naturalist Ariosto (1474–1533) said that Nature made the individual, and then " broke the die." Truly no two organisms are exactly alike, and these individual differences are grouped under the term *variation*. In other words, all organisms in their structural and physiological characters vary more or less in all directions, even though in general they closely resemble their parents.

Fig. 10. — Charles Darwin (1809–1882). Father of the theory of evolution.

Theory of Organic Evolution

History. — Thinking men during the past millenniums have in their religions explained how the present worlds came into being, and nearly all of these accounts have to do with *creations* through the acts of gods. In more recent times, naturalistic theories have been advanced, and these have to do with *evolution*, or the processes of unfolding and development of Nature.

With the rise of the sciences, and more especially the accumulation of knowledge regarding the succession of fossil faunas in superposed strata, each one of which is a different life assemblage from the previous one, there arose in explanation the theory of *Catastrophism and Re-creations*. This was brought into general acceptance chiefly through the teaching of the great Cuvier (1769–1832). In practice, the theory meant that in the past the entire earth had undergone catastrophes or revolutions, when all organisms were locally or universally destroyed. These were followed by times of crustal stability and re-creations of more advanced faunas than the previous one. In Cuvier's time, however, the geologic sequence was poorly

known, and the catastrophisms of a century ago are now interpreted as the "breaks," the locally absent records in the completed geologic sequence. Since then, the strata with their fossils that fill in these breaks have in the main been discovered elsewhere, and these often have the transition animals unknown in Cuvier's time. In this way the facts of nature were learned and the ground prepared for the evolution theory of to-day.

Aristotle, the greatest of Greek naturalists, rejected the idea of special creations and believed in the operation of natural law and not in chance or the survival of the fittest. He believed in "an intelligent design as the primary cause of the changes which have been wrought in nature. . . an internal perfecting tendency impelling organisms to greater and greater perfection" (Lull).

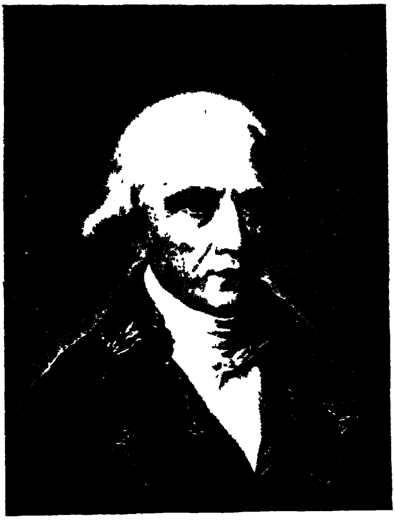

Fig. 11.—Jean Baptiste de Lamarck (1744–1829). Father of the theory of mechanical genesis in evolution.

In modern times it was Galileo, Newton, and Laplace who, gave the thinking world a scientific theory as to the evolution in the inorganic world; and Buffon (1707-1788), Lamarck, Darwin, Wallace, and Spencer who foreshadowed the present theory of organic evolution. It now seems strange that the educated public fought this theory so strenuously, and that it took almost a generation of thunderings by Huxley in England, Haeckel in Germany, and Gray in America to prepare the way for its acceptance. Now we see clearly that the theory of evolution is without doubt the grandest generalization of the nineteenth century. It not only transformed the method of study in Biology, Geology, and the social sciences, but as well has given a new point of view to all science, art, and even to progressive religions.

Jean Baptiste de Lamarck (1744–1829) was the father of the theory of mechanical genesis in evolution,—the use and disuse of structures, and the inheritance of acquired characters. In 1809 Lamarck held that the organism is shaped by the environment; that usage develops organs in the individual, which through disuse become atrophied and finally lost; that the characters acquired

during life are inherited; that there is a fundamental unity in the organic world; and that there is a slow but continuous progression from simple to complex organisms. To accomplish these things in nature, he said that all that is needed are matter, space, and a long time.

Charles Darwin (1809–1882), "the emancipator of human minds from the shackles of tradition," is by general consent recognized as the father of the modern theory of organic evolution. The essence of his theory, Thomson says, is in the two words *variation* and *selection*, or, as Wallace puts it, in *descent with modification*. Through his books, and chiefly the epoch-making *Origin of Species* (1859), came the conviction that life has been continuous, descending from previous life with change, resulting in the complex floras and faunas of to-day. His was the idea of organic evolution as opposed to supernatural creation.

Fig. 12. — Alfred Russel Wallace (1822–1913). With Darwin, the father of the theory of natural selection.

The Web of Life. — All Nature is interrelated and interlocked, and this is as true of the inorganic world as it is of life. We may illustrate this web of life by the following, taken from Thomson: The sun's energy has made plant life possible, and plants are to man his food, clothing, habitations, and in wood and coal his warm hearths, steam and power. Again, cats condition the extent of a crop of clover or honey, for they keep down the number of field mice, which in turn feed on honey, and a scarcity of honey means fewer bees that are so necessary to fructify the flowers of the clover. Finally, the dissemination of plague is largely conditioned by the presence of the house rat, and an absence of these rodents leads to better sanitary and healthier life conditions for humanity.

The Struggle for Existence. — Organic nature, in all of her wondrous beauty and astonishing variety, appears to the careless

observer to be in a condition of ease, play, and contentment. Play, however, generally means getting food, and contentment is at the expense of pain and death to another individual. Truly all organic nature is continually struggling to maintain itself, in the securing of food, in resisting unfavorable environmental conditions, in mating, and in the effort to rear its young. Death is inevitable, overtaking most of the organisms while they are still young, and hence few are maintained to maturity to propagate their own kind. The world is, nevertheless, and always has been fully populated, since each species unconsciously seeks at the very least to maintain its own numbers or to increase them. "A stock tends to increase in numbers," according to Conklin, "until it reaches the limits of its habitation, when it becomes fixed, since the means of subsistence is subject to the law of diminishing returns." More young are born each year than can possibly exist. Some individuals produce but a single offspring, while others cast upon the world a million or more during the season of reproduction. Life's struggle is exceedingly harsh toward the young; they are mercilessly weeded out because of unfavorable habitations and starvation, snapped out of existence by a predaceous enemy, or made sick unto death by extremes of heat or cold, or by bacterial diseases. *Success in life is the rare exception.* In a struggle so severe, any advantage, however slight, may therefore be decisive in prolonging the life of the individual and stimulating the origin of new variations. Nature constantly eliminates the unfit, and through the survival of the fittest, the species are maintained, though with constant alteration. The whole course of evolution, therefore, centers in the processes of reproduction, and the favored individuals transmit their valuable qualities to their offspring, generation after generation.

Fig. 13. — Thomas Henry Huxley (1825–1895). The great defender of evolution and exponent of the natural sciences.

Influence of Environment on Organisms. — Organic evolution "implies a mastering of all the possible haunts of life; it has been a progressive conquest of the environment" (Thomson). So long as the environment of organisms remains unchanged, they undergo comparatively little modification, and such conditions prevailed during long geologic times. However, as the earth's shell has been periodically raised into mountain ranges and the oceans have as often flowed widely over the continents, it follows that the environment of plants and animals has undergone repeated and vast alterations. When the seas flowed over the continents, the habitable areas, or *habitats*, of marine life were enlarged at the expense of the land floras and faunas. The struggle for existence among the land plants and animals was therefore made harder, and evolution was quicker among them. Contrariwise, when the seas contracted, the struggle among the marine forms was enhanced, due to diminished space, and on the lands the former mild climates were apt to change into more or less arid ones. Not only this, but many times mountains were thrown up simultaneously in many lands, thus bringing on great reductions of temperature, arid climates, and even glacial ones. Such changes led to the "critical periods" in the history of the earth, times especially fraught with danger to the organic world, and affecting deeply not only the life of the land but equally the shallow-water marine forms. Evolution was then especially rapid, blotting out floras and faunas that had long dominated the earth, and forcing the rise of new races which in their turn quickly attained mastery over their physical and organic environment. "Wherever there is life there is some degree of mind" (Thomson). (See also Chapter XXXII.)

The Pulsing of Life. — The paleontologist is deeply impressed with the periodic appearance of new stocks of plants and animals, connected in the main with marked changes of the environment. He therefore holds that it is the periodically changing physical conditions that are the greatest impelling force in organic evolution. On the other hand, the long intermediate times of equable and mild climate and nearly constant environment produce but slight specific alterations, the changes in one direction known as orthogenetic. Therefore to the paleontologist evolution appears at times to proceed far more quickly, and as it were by leaps and bounds. These are the times of quickened adaptations to meet the great changes in the environment, while a slow or even stagnant evolution accompanies the long intermediate periods. Accordingly, evo-

lution is not dependent on mere life activities, but mainly on the marked geographic, topographic, and climatic changes that periodically recur upon the earth.

Evidence Proving the Theory of Organic Evolution

That all of the manifestations and complexity in the organic world have come about through descent with modification is shown in the following facts: (1) The living organisms are not distributed at random throughout space, but exist where we find them because of prehistoric conditions (Geographic Distribution). (2) All organisms are related to one another and this determined relationship can be readily visualized in a genealogical tree wherein the degree of ancestral parentage is shown in the trunk, main branches, stems, and leaves (Classification. See Fig., p. 13). (3) In related adults the organization and structures are alike, and these are unlike in unrelated stocks (Morphology). (4) The lines of descent are in a measure repeated during the earliest stages of growth in the individuals (Embryology). (5) The appearance of plants and animals throughout the geologic past is in harmony with the theory of progressive evolution from the structurally simple to the more complex (Geology and Paleontology). These topics will now be discussed in detail.

Geographic Distribution. — According to Gadow, "The subject of geographical distribution is the dispersal of life in space and time. The key to the present lies in the past." A little insight into the living organisms soon reveals the fact that the kinds of plants and animals are not of universal distribution. Every one knows that elephants and lions are found only in Africa and Asia, and the giraffe only in Africa, that reindeer and caribou are restricted to northern lands, kangaroos to Australia, and humming birds to the three Americas. While this restriction is largely controlled by temperature, yet that is not the whole cause, for we know that the tiger of southern Asia lives also in Siberia, where it has fortified itself against the cold by the growth of a thick fur. Restriction of species is further controlled by mountain ranges, moist and dry climates, forest and open plains regions, and chiefly through isolation of the land masses by the oceans. These are the *barriers* of the biologist, which prevent free intermigration between areas. Another kind of barrier which confronts animals in their wanderings is exposure to the local diseases caused by parasitic organisms. However, these barriers do not explain, for instance, the present wide distribution of the bears in Europe, Asia,

and America, where they range from the cold north into tropical Brazil, and from Siberia into Alaska, lands that are now separated by at least a hundred miles of ocean surface. But when we are told that in the geologic past Asia and America were united by a land connection, a *land bridge*, and that both had a warmer climate than at present, it is readily seen that the bears could have spread from the former continent into North America and so finally into South America. In other words, the present geographic distribution of organisms is not wholly due to the environment of to-day, but is further conditioned by that of the geologic past (paleogeographic distribution).

Also, similar environments do not produce identical organisms. Life descends from life, and as it is slowly but constantly changing in response to the constant alteration of its environment, the forms change and under favorable conditions the individuals grow ever more numerous and spread in wider and wider waves of wanderings, though, on the other hand, some organisms continually succumb under the struggle for existence. Species originate locally, and though some may remain thus restricted, others spread from their *dispersal centers* into wider areas according to the favoring nature of their surroundings and geography. These conditions are the controlling factors underlying the dispersion of all life, whether of the land or of the waters.

Classification. — The very fact that there are individuals of a kind that can be grouped into species and these into genera establishes the view of relationship. The further fact that in many cases there are no distinct differences separating the species or even the genera is further proof of descent with change.

Morphology (from the Greek word for *form*, hence the science of form). — "According to the evolution theory, all higher organisms have descended from the lower by a process of transmutation. . . . This bond of union is first and foremost expressed in the morphological traits of the related species. For as the related animals (or plants) are descended from the same ancestral type, they must possess on the whole the same anatomical structure and organization, more or less modified in each individual case according to the life-habits of the organism. It is this fundamental identity of structure that we mean when we speak of the 'unity of type' in a given class of organisms, while the different parts and organs which are built on the same general plan in the various species are said to be homologous. In contradistinction, analogous organs are such as fulfill the same physiological function without possessing the same

anatomical structure, as, *e. g.*, the wing of a butterfly and that of a bird, which, though both serving for flight, are constructed each in a totally different manner" (Herbert).

Homologous structures offer the most striking evidence for the transformation of species. A good example is seen in the limbs of vertebrates, where the main muscles and bones are alike in a frog, reptile, horse, dog, or man. In detail, however, there are marked variations; in man, for instance, there are five fingers and toes, while the horse has only the third finger and toe remaining, although if we trace the ancestry of the modern horse into the geologic past we learn of fossil horses with three or four functional digits on each limb and with the rudiments of the remaining ones still present to show that the ancestral forms had the primitive five digits in use on each limb.

In the animals just mentioned we pass from homologous structures to *vestigial structures*, for the one-toed living horse still has in each limb the vestiges of the second and fourth digits, known as the splint bones. The same is true in the fossil horses, but in the oldest ones the splint bones are the vestiges of the first and fifth digits. The whales and porpoises of the oceans are descended from land mammals which had four legs adapted for walking, but the front limbs of these ancestors have been greatly modified in the living forms into swimming paddles, while the hind ones are to all outward appearance gone, although in reality the vestiges of them lie buried deeply in the flesh. In most of the snakes not even traces of any of the limbs are present, but in the python or boa there remain bony vestiges of the hind limbs. In the birds, similar loss of the front limbs can be observed, as, for instance, in the flightless ostrich, whose wings are not fully developed, while in *Hesperornis* of the Cretaceous (Chapter XL) there are no wings, but deep in the flesh lies a single bone, representing the former wing.

Through disuse once useful organs may be largely lost, never to be recovered by subsequent descendants. In many animals the use of remaining relics is not always easily discerned, for these *vestigial structures* are but traces of former important organs. In man there are 180 such vestigial organs which serve no useful purpose, and which prove his animal descent. The human embryo in its earliest growth has a distinct external tail, and in every adult there is the vestigial vermiform appendix, "a small blind process leading from the large intestine, which, serving an appropriate function in vegetable-feeding animals, survived as a useless structure in man, and is at times even a source of danger" (Herbert).

Law of Irreversible Evolution. — In the previous paragraphs it was shown how animals may lose certain structures. The parts once lost can not be redeveloped out of the vestiges in subsequent evolution, but are gone forever. However, similarly functioning ones may be developed anew out of other anatomical structures. For instance, all bivalves in their embryonic free life have two eyes that are completely lost when they become addicted to the water bottoms and the shells begin to appear. On the other hand, adult scallops, which are also bivalves, have a whole series of eyes along the anterior margin of their mantles. The fine eyes of adult cephalopods are totally different structures from those they have in their embryonic life. Whales in their adaptations to the oceans have completely lost their hind legs and do not use their modified front ones in swimming; they have, however, developed a wholly new mode of locomotion by their powerful fluked tails.

Embryology. — Embryology is the science which relates to the development of embryos, or the earliest stages of individual growth before the assumption of the distinctive form and structure of the parent. All living things begin their existence in a single cell that may be compared to the unicellular plants and animals, the most primitive condition of organisms; the original or mother-cell in the higher multicellular entities giving rise by repeated divisions to the adult specific organism. In this way each multicellular plant and animal recapitulates in a condensed and foreshortened way its ancestral history. This law was first formulated by the great German biologist, Haeckel, who termed it the *biogenetic law*, or *ontogeny*, and defined it thus: "The Ontogeny (development of the individual) is a short recapitulation of the Phylogeny (development of the race)."

Ontogeny illustrates "the lingering influence of a long pedigree, the living hand of the past, the tendency that individual development has to recapitulate racial evolution. In a condensed and telescoped manner, of course, for what took the race a million years may be recapitulated by the individual in a week" (Thomson).

In the highest vertebrates, including man, the embryos during their development pass through a series of transformations which represent roughly the evolutionary stages of their lower vertebrate ancestry. In the earliest of these stages there is hardly any difference between the embryo of a fish, salamander, tortoise, chick, hog, calf, rabbit, or man. This can only be explained on the supposition that all of these animals had fish-like ancestors. In the succeeding stages among the mammals, the embryos repeat

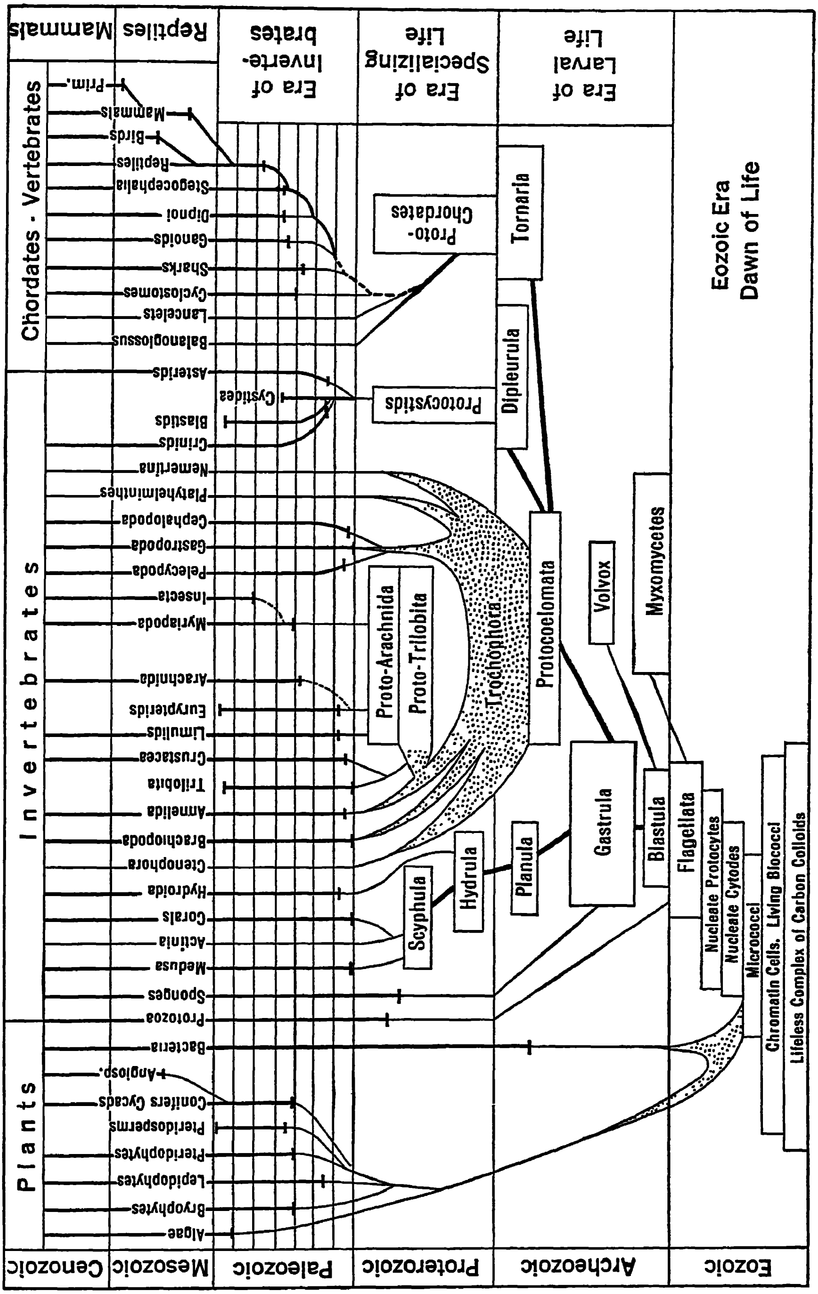

Fig. 14. — Diagram to show the time origins, phyletic interrelations, and geologic durations of plants and animals. Many of the Archeozoic kinds of animals named in the diagram are illustrated on Pl., p. 154.

practically only mammalian characters, thus showing that the ancestral history between the fishes and mammals has been eliminated, forgotten, and crowded out of their embryonic development.

Geology and Paleontology. — A great array of fossils is now known, and their appearance in geological time (chronogenesis) has been determined. Geology begins in darkness, with an absence of all fossils, but this very want of organic record is evidence that the earliest forms of life were perishable and could not have had the complexity of later organisms. In younger strata, however, there is an abundance of fossils, but nevertheless for a long time there is no evidence of land plants, and a land flora does not appear until still later times.

Not an insect is known until long after the appearance of the land floras. The earliest forms so far found were large plant-eaters and carnivores, but unlike the modern forms. They were followed by the most primitive of modern insects, the may-flies, dragon-flies, and true cockroaches; later appeared still higher types, but the dominant modern forms did not come until the rise of the flowering plants on which they are dependent.

Among animals, the first to appear were all water-breathers, and out of them arose the air-breathers. Not a shred of evidence for the existence of animals with backbones (vertebrates) is at hand until long after the backboneless forms (invertebrates) originated, the first representatives of the higher type being the fishes. Later came the higher amphibia or salamander-like animals, and out of them were developed the primitive reptiles. Reptilian birds with teeth appeared after the reptiles, and these but recently, geologically speaking, gave rise to the modern toothless birds. On the other hand, reptilian mammals originated earlier than the birds, and through a long process of evolution finally gave rise to the placental mammals, the highest type of animals. Finally, the line of mammals leading to man appeared first in the lemurs (monkey-like animals), shortly afterward came the true monkeys, and more recently arose the anthropoid apes and the ape-man. Study Fig., p. 47.

Such evidence must convince anyone of the fact that the organic world proceeded to develop in an orderly sequence from the simpler to the more complex types of structures and from the lower to the higher mentality. The higher intelligence had its origin, not in the sea but on the land, where the most severe of environments placed a premium on the ability to meet and master new

conditions. It was long in the making and not until geologically recent times did mind begin to evolve with wonderful rapidity in most of the mammals, and especially those in the line of man's ancestry. Contrast the intellectuality of the dinosaurs, rulers of the medieval world, with a brain weighing one pound in a body of thirty-eight tons bulk, and man, master of the modern world, with a brain ratio of four pounds to one hundred and fifty of flesh and bone!

The Meaning of it All

All theories as to the causes of organic evolution, Conklin says, agree in ascribing more or less importance to the influence of environment. Lamarckism maintains that changes in individuals are caused directly by changes in environment, that these individual changes are inherited, and thus bring about racial changes. Darwinism teaches that variations of every sort are caused by changed conditions of life, but that those which are injurious are quickly eliminated while only those which are beneficial and well adapted to environment persist and constitute the building materials of evolution.

The results of evolution may be summarized in three words: Diversity, Adaptation, Progress. *Diversity* is seen in the endless progressive, retrogressive, useful, indifferent, or harmful variations that species undergo. *Adaptation* is adjustment to conditions of life, of means to ends, and structures to habits, and is brought about through natural selection. *Progress* means increasing complexity of body structures and functions, increasing specialization and coöperation of the parts and activities of organisms.

The Truth of Organic Evolution. — The question is often asked by those unfamiliar with the work of biologists: Is the theory of organic evolution widely accepted by the students of organisms? The answer is that scarcely any worker in the sciences of Botany, Zoölogy, or Paleontology now rejects the theory; in fact, all work in these studies is based on the concept of life having continuously descended from life with change since it began on the earth.

"We could not teach geology without teaching evolution" (Berry). There is now no question about the truth of organic evolution as opposed to the theory of special creation. One of the leaders in organic evolution, Bateson, recently said (1921), "Our doubts are not as to the reality or truth of evolution, but as to the *origin of species*. Any day that mystery may be solved." In other

words, what is under discussion among the biologists is the method by which nature has brought about the manifold organic changes that we see. No more intricate problem confronts man. It is therefore not remarkable that the entire solution or even the main parts of it are not yet at hand. The old notion of eternal unchangeableness with occasional upheavals has forever given way to the newer idea of progressive development, not only in organic nature but in all matter.

The student of evolution may at present reserve judgment as to what *causes* evolution, and as to how the external and internal conditions bring it about. Nevertheless the paleontologist holds firmly to the belief that progressive and retrogressive evolution is largely caused by the environmental conditions, and the use and disuse of organs. He sees entire groups of new plants and animals appearing while old ones are vanishing, and this mainly at the times of marked geographic, topographic, and climatic changes. To him there are periodically recurring critical times when there is a remarkably quickened evolution, with the emergence of new floras and faunas. Through it all there is in the main an upward trend from simplicity to greater and greater complexity, from thoughtlessness to instinct and finally to reason. And the evolution of the cephalopods and trilobites, crinids and brachiopods, horses and camels, rhinoceroses and elephants, the many aquatic adaptations of animals descended from land-living ancestors, the independent invention of flight by fishes, insects, birds, mammals, and man, and the differently derived and constructed breathing organs of snails and slugs, scorpions and insects, amphibians, reptiles and mammals, all are to the paleontologist demonstrations that the changing environments and the will of organisms are of first import as causes for organic evolution. Collateral ones are use and disuse of organs, and mechanical genesis.

Of Charles Darwin, who first placed the doctrine of organic evolution on a firm scientific foundation, it has been said: "In all the glorious company of immortal dead whose earthly frames are gathered in England's great mausoleum, there is no other one who has done so much to modify the mind of thinking man" (Schmucker).

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CHAPTER V

CONTINENTS AND OCEANS

In this chapter we are to study the greater features of the earth's surface, the continents and oceans, and the interrelations of these parts among themselves and as the abodes of life (see Fig., below).

Major Features of the Earth's Surface. — The most striking characteristic of the earth's surface is its division into great land areas, the continents, and into vast oceanic basins. If there were no continents, there would be a universal ocean, and if the earth's surface had no inequalities of level, the depth of water would be everywhere about 8000 feet. Without land, there would be no terrestrial life, no higher plants than the seaweeds, and among the animals no higher vertebrates at all. The highest mentality of the world would at best be that of the squid or cuttle-fish and crab or lobster. Of sedimentary rocks, there would be almost none. Even the composition of the atmosphere would be of another character, with very little of free oxygen, and the oceans would be devoid of nearly all salt (sodium chloride). This being so, it is a question if life could have originated at all in such a fresh-water environment.

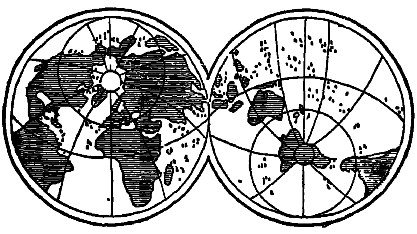

Fig. 15. — Land and water hemispheres. From Tarr's *Elementary Physical Geography* (Macmillan).

The outer shell of the earth is the rock sphere, in Geology spoken of as the *lithosphere*. Lying upon the latter, and to a very limited extent circulating within it, is the *hydrosphere*, or sphere of water; and outside of both is the envelope of gas and vapor known as the *atmosphere*.

There is an outer rigid portion of the lithosphere that cracks, faults, warps, and folds; it is known as the *stratosphere* (means composed of layers or strata of rock), or as the *tectonosphere* (means the shaping outer part of the lithosphere). Below the rigid portion is the very slowly mobile portion of the lithosphere.

Within the hydrosphere, above the surface of the lithosphere, and at the base of the atmosphere exists the *biosphere*, consisting

of the living organisms, the plants and animals. Collectively the organisms are also spoken of as the *bios*. The biosphere is the transition zone between the atmosphere and hydrosphere on the one side, and the lithosphere on the other. The carbonic acid of the air may be transformed into organic rock through the agency of plant life, and, as coal, take part in the formation of the earth's crust. Through the life of the waters, carbonic acid and sulphate of lime may be changed to limestone. As carbonic acid results from volcanic action, the hot internal material of the earth may, through plants, become living substances (Walther).

Parts of the Lithosphere. — In its largest features the surface of the earth or lithosphere is divided into lands, the continents (about 30 per cent, or 57,254,000 square miles), and great bodies of salt water, the oceans (about 70 per cent, or 139,295,000 square miles). To the north of the equator occur about three fourths of the total land areas (about 42,000,000 square miles) and these continents are grouped about the small Arctic Ocean. Accordingly the northern hemisphere is also known as the land hemisphere. Over the south pole lies the large continent Antarctica, and surrounding it is the frozen margin of the Antarctic Ocean, whose waters continue with undefined boundaries far into the northern hemisphere as the Pacific, Atlantic, and Indian oceans. The Pacific Ocean alone is greater by 10,000,000 square miles than all the lands combined.

In other words, the oceans now surround the six great continents (1) North America; (2) South America; (3) Eurasia, or combined Europe and Asia; (4) Africa, (5) Oceanica or Æquinoctia, comprising West Oceanica or Melanesia, Central Oceanica or Australasia (Australia, Tasmania, New Zealand, and the Fiji Islands), and East Oceanica or Polynesia; and (6) Antarctica (with a probable area, according to Murray, of 5,122,000 square miles).

The relative areas of the lithosphere above and below sea-level are as follows:

	Per Cent	
The highest peak is Mt. Everest in the Himalayas, 29,141 feet		
More than 6000 feet above sea-level........	2.3	Dry land area 30.4 per cent
Between sea-level and 6000 feet above......	28.1	
Between sea-level and 600 feet below.......	5.1	Area of continental platform 35.5 per cent
Between sea-level and 6000 feet below......	7.0	Water area 69.6 per cent
Between 6000 and 12,000 feet below..	14.8	
Between 12,000 and 18,000 feet below......	39.6	Actual oceanic basins 64.5 per cent
Between 18,000 and 24,000 feet below......	3.1	
The greatest known oceanic depth is near Guam, 31,600 feet		

Continents

Mean Elevation of the Land. — The mean height of the continents above the sea is given by Sir Archibald Geikie as about 2400 feet. Dana says that the material of the Pyrenees spread over Europe would raise the surface only 6 feet; and that of the Alps, although of four times larger area, only 22 feet. Finally, only 6 per cent of the lands (or about 3,300,000 square miles) is 3250 feet above sea-level, so trifling is the total surficial area of the present or visible mountains.

Total Amount of Erosion. — As all of the sodium chloride of the oceans has been derived from the lands through their weathering during the geologic ages, and as the percentage of salt in the average igneous rock is known, we have in these facts a means of computing the amount of such rock worn away in the course of the ages. According to Barrell, this is equivalent to 3.3 times the volume of all lands at present above the level of the sea.

Characteristics of Continents. — Dana defines a continent as "a body of land so large as to have the typical basin-like form, — that is, independent mountain chains on either side of a low interior." As the mountain borders of the continents vary from 500 to 1500 miles in breadth at the base, it follows that a continent cannot be less than a thousand miles (twice 500) in width. The wider border faces the larger ocean; in North America the Pacific Mountains face the Pacific Ocean, while the narrower Appalachians margin the continent on the Atlantic side. Between the latter and the Rocky Mountains lies the continental basin, a vast area drained by the Missouri and Ohio, which flow into the Father of Rivers, the Mississippi. As the Arctic Ocean is small and comparatively shallow, North America and Greenland in the far northeast are bordered by low and narrow mountains, known as the United States Range. On the south, the small Gulf of Mexico has its compensating elevations in the small east-west trending mountains of Arkansas and Oklahoma.

Grain of Continents. — The rocks of the lands usually have a definite strike, or alignment, and this is especially true in the areas of mountains of the present and past. This is the *grain* of the continents, as seen in the strike, igneous intrusions, rock flowage, schistosity, etc.; it is due to the various pressures which the continents have undergone during their long history, and to a shrinking earth. It is a fundamental character of all continents and gives hints of their former history and geography. (Ruedemann.)

Oldest or Nuclear Parts of the Continents. — Most of the present continents have been formed around ancient protuberances of the lithosphere, the nuclear lands, "the primeval, immovable cornerstones of the earth" (Emerson). For the most part these consist of very old igneous rocks and metamorphosed sedimentaries. They are the oldest lands that have remained more or less contin-

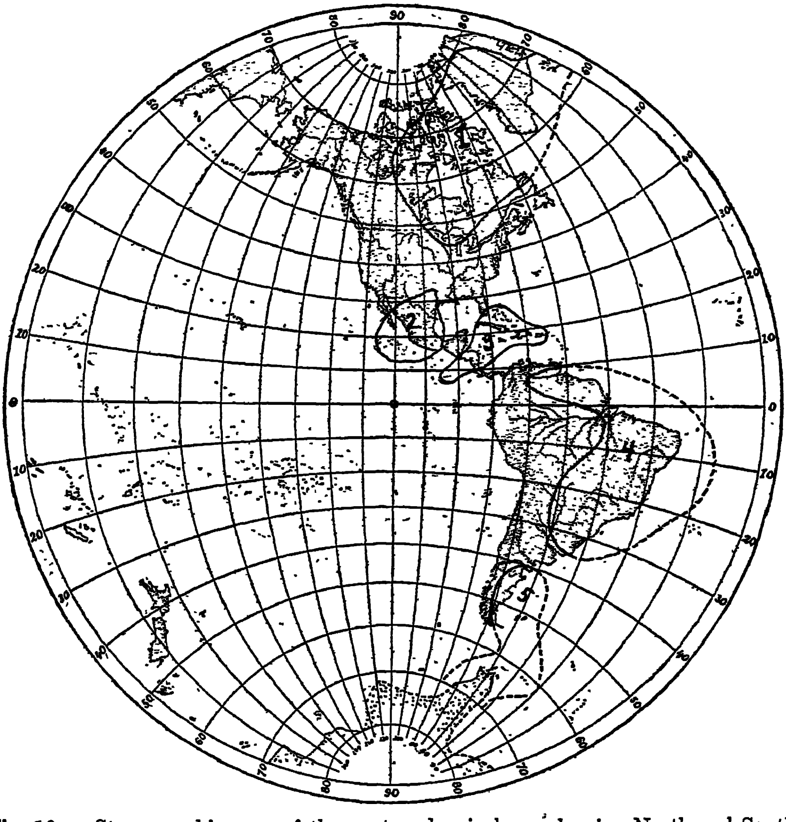

Fig. 16. — Stereographic map of the western hemisphere, showing North and South America, or the occidental lands, and Antarctica. After Penfield. The nuclear lands, or shields, indicated in outline: 1, Canadis; 2, Columbis; 3, Antillis; 4, Amazonis, including Guianis; 5, Platis.

uously above sea-level, and it was against these nuclei that many of the mountain chains have been pressed. In general, however, these nuclear continental masses are not the areas from which the formations of the last half of the earth's history have derived their sediments, for nearly all of them during this time remained low in relation to sea-level. In other words, the sediments have come from the periodically raised mountains. The nuclei appear to have come

into existence before Proterozoic time. The word *shield* was applied to them by Professor Eduard Suess of Vienna in 1888, because the two best known examples, the Canadian and Baltic masses, have the form of a depressed shield. *Nucleus* of Dana and Willis is an older and better term. They have also been called cores, bosses, and coigns.

There are at least thirteen of these ancient land masses (see Fig., pp. 55, 57), and to distinguish their names readily from those of the oceans it is proposed in this chapter to accept the method of Arldt, ending the names of the lands in *is* and those of the oceans and seas in *ic*. Three of the shields occur in North America: *Canadis, Columbis,* and *Antillis;* three in South America: *Guianis-Amazonis,* and *Platis;* Africa has *Ethiopis* and *Verdis; Lemuris* is peninsular India and Madagascar; the two of Eurasia are *Baltis* and *Angaris;* Oceanica has *Bornis* and *Australis;* and finally there is *Antarctis,* at present a high mountainous ice-covered land, considerable parts of which rise to an altitude of about 10,000 feet above the sea.

Permanency of Continents and Ocean Basins. — In the earlier days of Geology it was held that there was no stability in continents and oceans as such, and that there had been complete interchange between them. Even Sir Charles Lyell taught that all parts of the ocean bottoms had been land. Now, however, most geologists hold with Dana that the oceanic basins and the continents have in the main, although not at all in detail, been permanent features of the lithosphere at least since the close of Archeozoic time. This hypothesis was first announced by Dana in 1849. There is likewise much agreement among geologists in the belief that the oceanic basins are vast sinking fields of heavier materials, also spoken of as the *negative areas* of the lithosphere, because the sum of their crustal movements is downward; and in general it appears that the oceanic basins have gradually attained not only greater depth but greatly enlarged area as well. On the other hand, the continents are the rising masses of lighter rocks, and for this reason are also called the *positive areas,* because the sum of their movements is upward (see Pt. I, p. 242). Of the known land surfaces, about one half appear to have the folded structure, but if the younger unfolded rocks were removed, it would be seen that the whole of the continents consist of folded and igneous rocks. Of these two great features of the lithosphere, the oceanic basins are the more permanent, while the continents are either locally enlarged or great masses of them are warped under or fractured and depressed beneath the oceanic level.

It seems that since Archeozoic time about 25,000,000 square miles of land have gone permanently beneath the oceans. That the internal forces of the earth have wrought great changes in the outlines of the continents and therefore in the shapes of the oceans as well will be shown in subsequent pages. In general, it may be

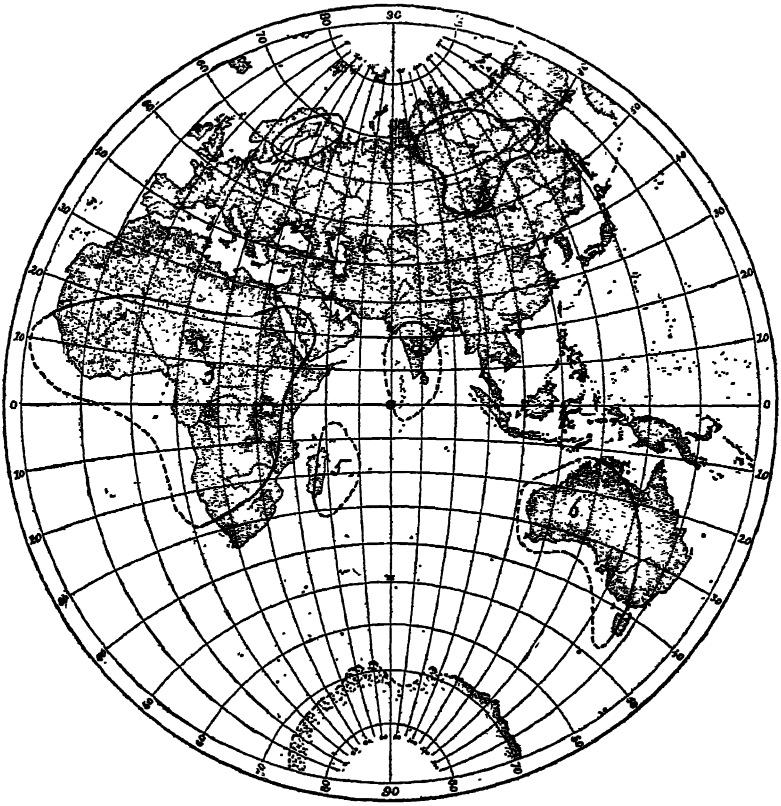

Fig. 17. — Stereographic map of the eastern hemisphere, showing Eurasia, Africa, and Oceanica, or the oriental lands, and Antarctica. After Penfield. The nuclear lands, or shields, indicated in outline: 1, Baltis; 2, Angaris; 3, Ethiopis, including Verdis; 4 and 5, remnants of Lemuris; 6, Australis. Bornis is not encircled; it includes Borneo and a part of the South China Sea.

said that oceans are the most permanent areas and that they have grown larger at the expense of the continents. "The continental masses of the present day are recognizable in Precambian time, and these early continents occupied much larger areas than their recent descendants" (Ruedemann). The greatest changes have taken place in Oceanica, southern Eurasia, Antarctica toward Aus-

tralia and South America, and in the central Atlantic and northern Indian oceans.

The proof that there has been no complete interchange between the continents and oceans is seen in the following facts: (1) On the continents there are almost no deposits of deep-sea origin, and the few isolated cases met with occur only on the margins or on continental islands.

Geologists have long sought on the continents for geologic sediments comparable to those now forming in the great abysses of the ocean, but to no avail. The German geologist Walther, who has carefully examined recent abyssal sediments, in his geologic studies has considered repeatedly whether any fossil rock possesses abyssal characteristics, and nowhere has he met with such of Paleozoic or Mesozoic age. Sir John Murray also failed to find large areas of oceanic rocks. However, a microscopic and chemical analysis of certain deposits on islands such as Barbados (here 1200 feet above sea-level) and Trinidad of the American mediterranean, Sicily and Malta, Borneo and Timor, and possibly Haiti, Jamaica and Cuba, shows that oceanic deposits of Cenozoic age occur on them. Chamberlin says: "The cases in which true abysmal deposits now appear above the sea-level do not, when all are put together, appear to attain in area so much as one per cent of the total earth surface. Moreover, nearly all of these oceanic deposits lie in the zones of exceptional crustal instability."

(2) The marine deposits on the continents are nearly always those of very shallow seas, in fact, not at all unlike those now accumulating on the continental shelves, or in Hudson Bay and the Baltic Sea. Further proof of this is given by the fact that the contained fossils indicate that the life was all of shallow-water types. If there had been complete interchange, on some continent there should be preserved a long and unbroken oceanic record in both the deep-sea sediments and animals, but nowhere has such a series of materials been discovered. (3) It is now established that the lithosphere is denser and therefore heavier beneath the ocean basins than under the lands, making it impossible for them to have interchanged their positions without destroying the density equilibrium of the outer shell.

Deep troughs or geosynclines have, it is true, been repeatedly developed within the continents, near their margins, but even though some of these have in places subsided as much as 70,000 feet, yet at no time have they held other than very shallow seas. This is proved by the character of their sediments and the entombed fossils. Stated in another way, there has been subsidence with compensating sedimentary accumulation. This is certainly true for the Appalachic and Cordilleric geosynclines, out of which

there eventually arose the Appalachian and Rocky Mountain systems. See Chapter X.

Two Types of Continental Borders. — Suess, Von Richthofen, and their followers, have pointed out that there are two general types of continental structures. The subsiding Pacific, on the one side, and the Indian and Atlantic oceans on the other have produced distinctly different geologic and geographic results. Briefly, the facts are as follows:

The Pacific border areas are usually concordant and follow the trends of the folded mountains bounding this ocean. On the other hand, the Atlantic and Indian border areas are either neutral or are discordant with the structural trend of the coasts.

In general, the rock strata of the Pacific borders are of more recent times, Mesozoic inland and marginally Cenozoic, while those of the Atlantic are oftener of more ancient formations across which discordantly lie the young geologic deposits. Along the Pacific shores there is therefore a parallelism and a readily perceptible dynamic connection with this subsiding ocean, while the margins of the Atlantic and Indian oceans have no such relationship, since the shorelines cut across ancient nuclei, old mountain ranges, and elevated table lands.

Examples of Continental Fragmenting. — As the ocean basins are the more permanent features of the earth's surface and as they are the periodically sinking areas, it is to be expected that more or less large parts of the ancient continents should have been dragged beneath the waters. In this connection we do not, however, have in mind the mythologic continent Atlantis, since there are no scientific data proving its existence. As a true example of continental fragmenting may be cited *Madagascar*, a great island, 975 miles long, with an estimated area of 230,000 square miles, lying in the Indian Ocean off the east coast of Africa. No naturalist doubts its former connection with Africa, because of their similar animals, and yet the channel of Mozambique which now separates it from the mainland is from 240 to 600 miles wide, and represents a land area that has gone down to a depth ranging between 5000 and 10,000 feet. To the northeast of Madagascar lie many small islands, the Seychelles, and to the northwest occurs the Comoro group, all of which are also held to have been parts of Africa and Madagascar. Not only this, but many biologists and geologists hold that all of these lands are but parts of the comparatively recent land Lemuris (see Fig., p. 57).

Another striking example is *Japan*, all of which was a part of the Asiatic continent previous to the Cenozoic, and parts of it remained connected as late as the Miocene. Now the Island Kingdom is separated from the mainland by the Sea of Japan, which is about 600 miles across in its widest part, and over 1000 miles from northeast

to southwest. This great downfaulted and sunken field is in general now a shallow sea not much over 650 feet deep, but eastward of the Gulf of Korea there is an overdeepened trough approximately 275 by 325 miles across, having a depth exceeding 10,000 feet.

Africa is unlike most of the continents in that it is a nuclear land, being a series of elevated plateaus ranging between 3000 and 6000 feet, and without marginal folded mountains that are younger than the early Paleozoic. In the northwest of this continent are the Atlas Mountains, actually a part of Europe, and the only ones in Africa of Cenozoic making. Southern Africa retains the roots of very ancient mountains, none of which are younger than Devonian time. Africa is the continent least invaded by the oceans, and its geologic recordings are in the main in continental deposits. It is, in fact, a land of fresh-water and intermontane deposits. The Mesozoic and Cenozoic seas invaded Africa widely only in the north and very sparingly along the east and west coasts. The African continent is a great elevated segment or block of the lithosphere with the geologic appearance of broken-down eastern and western margins. The faulted nature of its coasts is further seen in the fact that they are singularly free of large indentations and harbors. Finally all of eastern Africa, Arabia, and Asia Minor is faulted and rifted in a tremendous way, showing clearly the effects of the inbreaking of the Indian Ocean into greater Africa.

South America, on the contrary, has all along its western coast, in the high Andes, the elevated border required for a continent, but along its east coast we seek in vain for folded mountains younger than the Proterozoic, and it is therefore held by many of the ablest geologists, that northeastern South America across to Africa has gone down into the Atlantic.

Gondwana Land. — The broken-down and submerged parts of the continents referred to above (Africa and South America) are parts of a former great transverse equatorial land, and as there will be occasion to refer to this land from time to time, it is desirable to introduce the subject here.

Besides the facts given above, there is much other evidence of a geologic, paleontologic, and zoölogic character relating to the distribution of plants and animals since the Paleozoic, tending to show that Brazil was once widely connected with northwestern Africa across what is now the deep Atlantic Ocean. This lost continent is the *Gondwana Land* (from a district of the same name in India) of Neumayr (1883) and Suess (1885) and of the zoögeographers, a vast transverse land stretching from the northern half of South

America across the Atlantic to Africa and thence across the Indian Ocean to peninsular India, including Lemuris. It was in existence throughout the Paleozoic, but the Atlantic bridge and Lemuris sank into the oceans during the Mesozoic. Gondwana when complete was comparable to another transverse land of the north, *Eris* or Holarctis, which existed when North America was continuous with Greenland and Eurasia across Iceland to the British Isles (see Figs., pp. 431 and 555).

Mechanics of Continental Fragmenting. — Until recently, geologists have not been able to explain how continental masses may be dragged down or broken up and faulted into the depths of the oceans. The following explanation is by the late Professor Barrell, who was working on this problem at the time of his passing; the evidence is partially presented in *The Evolution of the Earth and its Inhabitants,* 1918.

In the rift valleys of eastern Africa, Death Valley of southeastern California, and the Caspian Sea of Russia, is seen the evidence of down-fracturing of great inland areas. Of the same nature are the riftings letting in the ocean in the areas of the Red Sea, Gulf of California, and west of Greenland in Davis Strait. From these cases we pass to great horsts like Madagascar, previously described.

To accept the foundering of land masses like those just mentioned, and more especially that of western Gondwana, there must be shown a process of internal loading or weighting of the rocks sufficient to cause them to settle down. It is thought that from 3 to 5 per cent of added weight is sufficient. It is now well known that parts of continents have been made lighter through intrusion of vast granitic bathyliths. The Rocky Mountains area previous to the Miocene tended to remain near sea-level, and since that time has been raised between 6000 and 11,000 feet. There would appear to be evidence here of a regional decrease in density in late geologic time, and the cause appears to be the rising of vast volumes of molten acidic magmas, along with the expansion of the cover rocks caused by the accession of heat, causing the area to rise from one to two miles into isostatic balance.

The specific gravity of igneous rocks varies between 2.70, the average of acidic granites, and 3.30 for the extremely basic types, the pyroxenites and peridotites. Granites have from 65 to 75 per cent of silica, diorites 55 to 65 per cent, and gabbros 45 to 5 per cent. There is here, therefore, a density variation amounting to 20 per cent.

If the earth is layered in density, such heavy masses would presumably originate deeper than those which are more siliceous. The siliceous also give off basic fractions by differentiation, but the exposed intrusives on the continents are mostly granite, and the basic portions represent a smaller volume. Great intrusions of basic magmas rising from the deeper interior would, under the principles of isostasy, produce subsidence.

When the lighter igneous rocks are intruded, they dome the overlying rocks, but in the great intrusions of gabbro at Sudbury, Ontario, the form of the rising mass is saucer-shaped, concave upward. It appears that the floor subsided under it during or after the intrusion, and accordingly also the roofing rocks. This form is the opposite of a laccolith, for the latter make domes. This fundamental distinction in form appears to be related to the high density. Being

denser than the surrounding rocks, such magmas have settled down; Grout has named them lopoliths. The Lake Superior area of gabbro is a far greater lopolith and has given rise to a much larger basin than that of Sudbury. A yet larger area of basic extrusion and intrusion into granitic rocks is that extending from western Greenland across to Iceland and Scotland. In this region, 1800 miles across, occur vast basaltic flows ranging in depth up to 10,000 feet. Their age appears to be Oligocene and early Miocene. Since then, this land of Eris has faulted on a vast scale and broken up into the geography seen to-day.

Another area of similar weighting and downbreaking is that of Lemuris, or the region of the Indian Ocean. Here the evidence is presented by J. W. Gregory in his book, *The Rift Valleys and Geology of East Africa*, 1922. It is also presented in broad outlines in this book in the chapter on the Upper Cretaceous. Still another is Brazil, described in the chapter on Jurassic time.

Oceans

The Five Oceans. — Oceans are the beginning and end of the rivers of the lands, and the sun furnishes the energy that lifts the waters into circulation. The word ocean is of Greek origin, and came to mean the great outward sea, the Atlantic, as distinguished from the inward sea, the Mediterranean. The ancient peoples of the Mediterranean knew of but one ocean, the Atlantic, that to them surrounded the stationary flat earth. The word ocean now has reference to the connected bodies of marine water that envelop the earth, of which there are five, Pacific, Antarctic, Atlantic, Indian, and Arctic.

Mediterraneans. — The mediterranean waters are also to be considered as oceanic areas, since they are not only large but also very deep, though never so deep as are the deepest parts of the oceans. These seas are, in fact, parts of the oceans, but are long and narrow, and more or less widely enclosed by continents. The typical example is the Mediterranean, lying between Eurasia and Africa; it is also known as the Roman mediterranean, the latter part of the name, meaning a sea in the middle of the land, coming down to us from the ancient nations which once ruled its borders. It figures largely in Historical Geology, and we shall have much to say about it under the name *Tethys*. Another but less typical example is the American mediterranean lying between the three Americas and walled off from the outer ocean by the Greater and Lesser Antillean islands and South America; it includes the Caribbean Sea and the Gulf of Mexico.

Area. — About 70 per cent of the surface of the earth is covered by oceans, but as the continents are more or less submerged about their edges, these marginal portions down to 600 feet are also truly

parts of the continental platforms (Fig., p. 77). Accordingly, the actual oceanic areas occupy somewhat more than 65 per cent of the surface of the earth, or roughly 140,000,000 square English miles.

Arranging the areas according to depth, Murray's table is as follows:

Depth in feet	Square English miles	Percentage
0– 600	9,750,065	7.0
600– 3,000	6,964,750	5.0
3,000– 6,000	5,010,185	3.6
6,000–12,000	26,915 000	19.3
12,000–18,000	81,381,000	58.45
18,000–24,000	9,058,000	6.5
24,000–31,614	216,000	0.15
	139,295,000	100.00

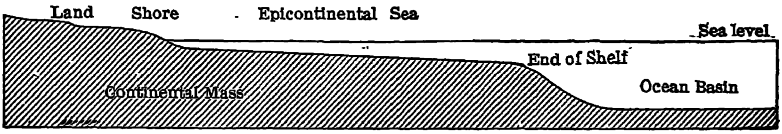

Fig. 18. — Diagram showing the different zones of the ocean. After Pirsson.

It is very important to bear in mind that nearly 70 per cent of the earth's surface is covered by water, and hence any marked movement of the earth's outer shell changes the relation of the shorelines to the lands. Such crustal changes were common throughout the geological ages and were especially effective in causing the oceans to spill widely over the continents, or to retreat and make the lands larger and more protuberant.

The Continental Shelves. — The continents are more or less submerged about their margins, and the area under water down to the 100-fathom (600 feet) line is truly a part of the continents, because it is only beyond this that the descent is rapid down the continental slopes into the oceanic depressions. For more detail see Fig., above. These marginal shallow-water areas are known as the continental shelves, and have an areal extent of less than 5 per cent (9,750,000 square miles, according to Murray) of the earth's surface, or 7 per cent of the oceanic areas. Therefore, the continental platforms have an area of less than 35 per cent of the lithosphere, while the remainder, of more than 65 per cent, is occupied by the actual oceanic basins (see Fig., p. 77).

Usually the depth of water over the continental shelves is taken as 100 fathoms, but Daly (1915) states: "The charts of the world show the break of slope on the shelves to be near the forty fathom line." Barrell (1915) also takes this view.

The reason why there are continental shelves, and why these are said to terminate at a depth of 600 feet, is because it is at this depth that the ocean storm waves cease to act on the bottoms of the seas. The areas of the continental shelves are, therefore, the regions of agitated waters bordering the lands and capable of holding mud in suspension to depths of not over 600 feet (see Fig., p. 63). The mud-mantled slopes of the ocean basins mark the slow settling of the mud from the waters beyond the reach of wave agitation. Consequently, in all ages the continental shelves must have been constructed at this depth facing the open oceans.

Depth and Volume of Oceans. — Below about 12,000 feet are the submerged oceanic plains with their swells, ridges, and peaks, making up about 65 per cent of the oceanic areas. For more detail, see pages 113–116 of Pt. I of this text-book.

From the above we learn that most of the oceanic areas lie below 6000 feet, and that more than 65 per cent are deeper than 12,000 feet. Areas with a greater depth than 18,000 feet are called *deeps*, of which fifty-seven are now known (see page 91 of Pt. I). The deeps are of two kinds: (1) the areally greater central deeps that are large, basin-like, down-warped regions going to depths of 24,000 feet; and (2) the more marginal troughs that are long and narrow, going to 31,600 feet. The latter, the *foredeeps* of Suess, are seemingly down-faulted regions situated near the continents and compensatory to the adjacent uplifted mountains.

The mean depth of the oceans is placed at 13,000 feet, and the volume of all the oceanic waters is said to be fifteen times greater than the mass of land protruding above sea-level. If all the deeper parts of the oceans were filled by solid material up to the estimated mean depth, it is said that there would result a universal ocean, covering the entire earth to a depth of 1.5 miles. These facts are recited here not only to impress the student with the immense volume of water when contrasted with the small mass of land above sea-level, but further to show, since the waters are mobile and cover nearly three-fourths of the earth's unstable surface, why it is that the oceans are enabled so readily to overflow the lands upon relatively small changes in the elevation of the crust. As the oceans are all connected one with another, a movement of the bottom of

any one basin affects the oceanic level in all, raising or lowering the strand-line everywhere simultaneously (eustatic movements).

Original Source of Water. — According to the Laplacian theory of earth origin, the ocean waters were regarded as primordial and originating with the primal atmosphere. Following this view, the assumption would be that the original oceans were not only as large in volume as they are now, but even larger, for all of the water in the outer shell of the earth must have soaked into it from the oceans. This theory is no longer acceptable, and it is now held that the ocean waters have been gradually added to the surface of the earth through the volcanoes and thermal springs. In other words, most of the oceanic water was originally water occluded or dissolved in the deep earth, and through volcanic action this *juvenile water* (steam) has been liberated and added to the already accumulated or *vadose water*.

Barrell states it as probable that from 25 to 50 per cent of the present oceanic waters have been added during Archeozoic and Proterozoic times, and during the Paleozoic from 5 to 10 per cent more. This therefore means that about 50 per cent of the water present on the surface of the earth had its origin previous to Archeozoic time.

Oceanic Level. — In general practice we speak as if there were a mean sea-level. There is, however, no such condition as a perfect spheroidal oceanic level, or a water surface equidistant throughout each circle of latitude from the center of the earth. Nevertheless, recent researches indicate that the differences of level at different points of the sea-surface do not depart more than 100 or 200 feet from a true spheroid of revolution. This subject is discussed further on page 235 of Pt. I under "datum plane."

There can not be spread over the entire lithosphere a sheet of water of equal depth, because the earth rotates and is locally heterogeneous in density, is flattened at the poles, and has an uneven surface. Furthermore, the edges of the continents attract the waters upward to them, while the mass of the earth attracts the waters downward. When a great mountain range arises, like the Andes, the water level must rise all along the coast of these mountains, and when these ranges are worn away, then again the water level must sink.

Oceanic Level during the Geologic Ages. — The mean oceanic level in the sense of a flooding plane over the continents has also fluctuated considerably throughout the geologic ages, and the times of these inundations since the beginning of the Paleozoic are now beginning to be deciphered. These, however,

are the smaller pulses of the oceanic levels, for there appear also to be long-enduring times when the mean of the strand level is either low or high. During the Archeozoic the total of the land areas appears to have been greater than at any other time, and while there were times of wide oceanic flooding during the Proterozoic, yet the continents stood in the main well above the mean of the oceanic level. Toward the close of the Proterozoic, all of the present continents appear to have been completely emergent, since nowhere is there found a marine record until the beginning of the Paleozoic. To emphasize this absence of record, Walcott has named the interval *Lipalian time* (see Chapter XIII) In the Paleozoic the mean of the oceanic level was high, but in the Permian it sank and it did not rise again widely over the lands until middle Jurassic time. The fluctuating floods continued to rise well into Cretaceous times, but toward the end of the Mesozoic, the waters subsided. During the Cenozoic, and especially after the Miocene, the continents were mostly emergent, and the climax was in the Pleistocene. The oceans are again tending to submerge the lands.

The cause for such long-persisting changes in the oceanic level is not yet known, but they may be due in minor amount to unloading of the protuberant lands into the oceanic basins, and mostly to the constant increase of the volume of water through the additions from volcanoes. On the other hand, the greater fluctuations have been explained as due to periodic deepening of the oceanic basins, but as they have also become wider through continental fracturing, this twofold volume increase should have made the continents more emergent than they have been. In other words, the oceans seemingly have long had their present mean depth, and the increase in the volume of water has been compensated for by down-sinking parts fragmented from the continents. Continental fragmenting works in coöperation with isostasy to maintain the residual continents above the mean of the oceanic level.

Composition of Ocean Waters. — That the ocean waters are quite salt when contrasted with the "fresh waters" of the rivers and lakes is well known, and the subject has already been discussed on page 91 of Pt. I. The salinity is somewhat variable from place to place, even in the oceans proper, is markedly so along the margins of the oceans where the rivers dilute the sea-water, and is most so in shallow areas under dry climates where concentration may go on continually. The salinity, therefore, may vary from the average of 3.5 per cent and range from less than 1 to over 4 per cent. The composition of the salts is given on the page referred to above.

All of the salts and the nitrogen in the sea as well have been brought down by the rivers, as discussed on pages 45 and 161 of Pt. I. Through the action of organisms the magnesium, lime, silica, and nitrogen are taken out of the sea-water, while the clays take up the potash, about as fast as supplied; the common salt, however, seems to have increased constantly in quantity.

The great volume of carbon dioxide in the ocean, the main foodstuff for plants, has been absorbed in part from the atmosphere and

probably in largest amount from submarine volcanic action during long geologic time. This juvenile CO_2 would naturally be retained by the seas. The free oxygen so necessary for animal life has also been absorbed in part from the atmosphere, but the greater amount has come from the carbon dioxide through the action of growing plants. It is thought that nearly all of the free oxygen of the air has been dissociated out of the CO_2 by living plants in the oceans and on the lands. The oxygen and CO_2 are less abundantly absorbed and retained in the warmer waters of the tropical seas.

Waters rich in calcium carbonate maintain, as a rule, a more varied life than do other waters. Such are especially favorable for organisms that use much lime in their hard parts, e.g., the corals and molluscs; even the crustaceans prefer such waters.

Ocean Currents and Temperature. — The earth rotates on its axis from west to east with a speed, in the equatorial region, of about 1000 miles per hour, while at the poles it becomes nothing. This movement, combined with the effects of the temperature differences of the zones, sets up the well-known trade winds of the tropics that blow rather strongly and constantly toward the equator and to the west, and so drag along the warm tropical surface waters. These in turn impinge on the eastern sides of the continents and are then variously deflected, in the main according to the shapes of the lands, causing great streams of heated water, or oceanic currents, to flow toward the poles as previously described, pages 92 to 94 of Pt. I. In this way the currents assist not only to equalize the temperature and salinity of the sea water, but also to warm the air in the higher latitudes and to spread the life of the oceans. At the same time the polar waters, receiving but little solar heat and cooled by their great fields of ice, flow equatorward, and since they are heavier than the warm tropical waters, sink beneath them into the depths of the oceanic basins. At the surface the temperature varies from about 80° at 5° north latitude (the warmest area) to about 32° at the poles.

Besides the great ocean currents there are many others of varying intensity set up by differences in temperature of the air and water, differences in the pressure of air and water, and varying degrees of salinity, and still others caused by the winds, the waves, and tidal action. "The sea is eternally restless." At the surface the Florida current of the Gulf Stream at its narrowest place, 44 miles, between the Bahamas and Florida, has a mean annual flow of 72 miles per day, but during the warmest and coldest months this rises to 120 miles per day. Northward between the Atlantic States and Ber-

muda and east of New York the rate of flow is about 48 miles per day. When less than halfway across the Atlantic, the streaming becomes less and less farther northeastward. From this rapid and exceptional streaming, the rate of flow or *ocean drift* ranges down to zero. Around headlands the water may flow as fast as 6 miles per hour. In depth the surface currents penetrate very variably, and in general the stronger currents are near the lands along the continental slopes, oceanic islands, and submerged ridges. As a rule, the penetration is less than 1000 feet, but in the Azores strong currents still exist at 2600 feet. In the tide-swept straits between the Canary Islands currents are present at 12,000 feet, and off the continental slope of Ireland they occur at 6000 feet. Therefore the ocean currents sweep the higher swells and ridges of the bottom clean of ooze, and level the bottoms into monotonous, undulating, abyssal plains.

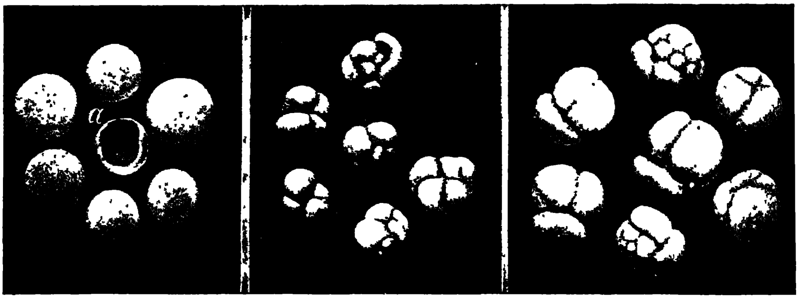

Fig. 19. — Three species of Foraminifera washed out of Globigerina ooze. × 12. *A*, *Orbulina; B* and *C*, *Globigerina*. After Flint.

Dispersion of Life by Currents. — It is a well known fact that nearly all marine animal life begins as minute and usually transparent larvæ. These float or feebly swim about for a time, up to several weeks in duration. In this way they may be carried by the great ocean currents many hundreds and even thousands of miles away from where they were born, and into the colder regions of the "roaring forties" where they can not maintain themselves because of the polar currents or the reduced temperatures of the winter months. The larvæ of West Indian corals are thus carried to Bermuda and have also adapted themselves to the most northerly small reefs off Beaufort, North Carolina. Along the coast of New England are found during the summer months not only larval but as well mature southern foreigners such as jelly-fishes,

Physalia (the Portuguese man-of-war), ophiurans, crabs, and other marine types. During the long geologic times when the earth has a nearly uniform mild climate, this oceanic dispersion of life is greatest, and because of these favorable conditions the marine faunas then have a more or less cosmopolitan distribution.

Light Penetration. — Since it is the green plants which assimilate inorganic matter into their living substance, and since animals depend on plants for their subsistence, it becomes necessary to know to what depths the sun's kinetic energy penetrates into the oceans. Verrill relates that he has dredged red algæ two inches tall attached to bowlders at a depth of 480 feet off Eastport, Maine.

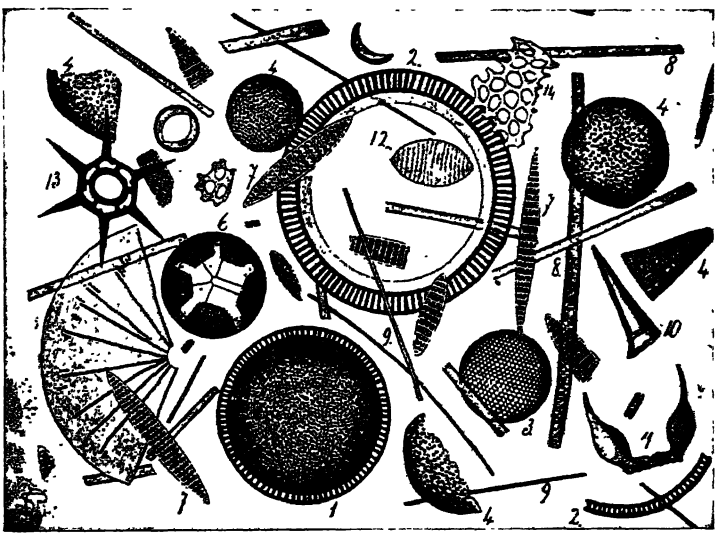

Fig. 20. — Many species of Diatoms (algæ) washed out of Antarctic Diatom ooze. × 300. From Krümmel's *Oceanographie.*

White objects can be seen in the clear tropical waters with the unassisted eye down to 200 feet, and coral reefs to 145 feet. Here the sun's rays enter nearly vertically, but toward the poles the angle is ever more slanting. Therefore, the vertical penetration is much less away from the equator, and at 67° north latitude the bottom can be seen in clear water only down to 80 feet. However, through the aid of photographic plates, it is now established that considerable quantities of light (ultra-violet and blue rays) in the tropical regions go down to 3250 feet, and some even to 5000 feet. These rays, however, are not usable by the assimilating plants

It is probable that the red, orange, and yellow rays made use of by plants in photosynthesis (i.e., the making of protoplasm through light energy) do not go in depth much beyond 600 feet. The portion of the ocean penetrated by sunlight is, therefore, spoken of as the *diaphanous region*, or the zone of transparency. It is also the region of photosynthesis, where the green plants change inorganic substances into organic structures. The dark region, where

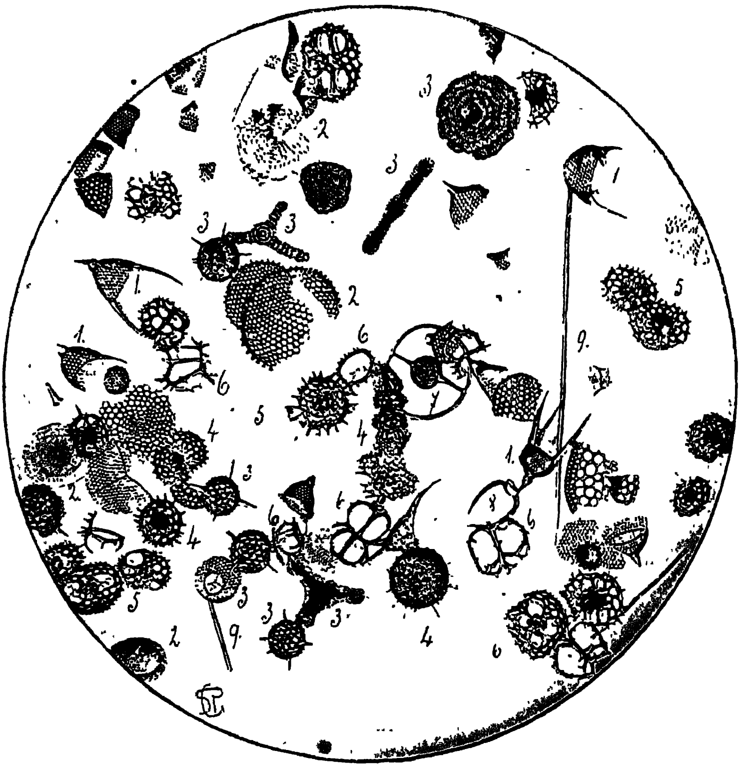

Fig. 21. — Many species of Radiolaria washed out of Radiolarian ooze. × 60. After Krümmel.

plants do not live, is known as the *aphotic region*, or the zone where sunlight is absent.

Oceanic Muds and Oozes. — The continental edge is also the *mud-line*, for everywhere over the ocean bottoms only fine-grained mud is being deposited; on the continental slopes, green and blue muds, coral mud, and volcanic ash of coarser grain (see p. 113 of Pt. I, and Fig., p. 71 of Pt. II); and elsewhere, green, blue, and red oozes of the finest grain. The mud of the continental slopes is

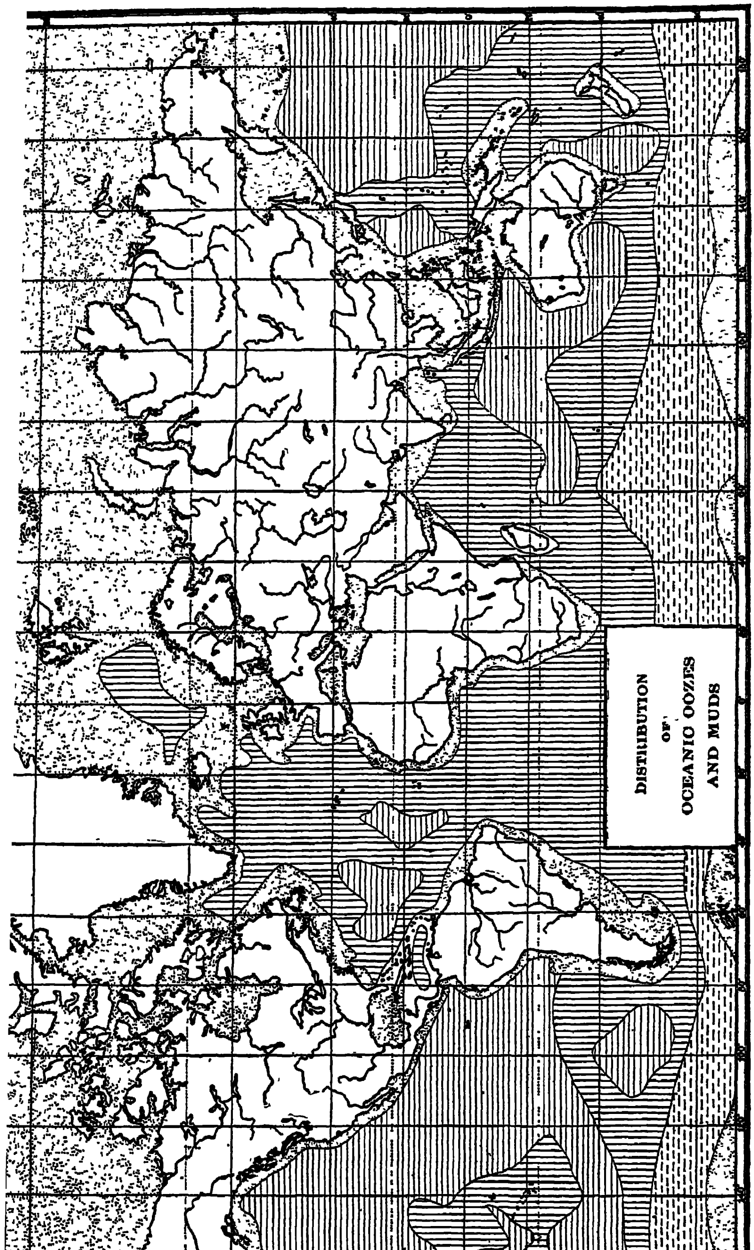

Fig. 22. — Distribution of oceanic oozes, on Mercator's projection. *Dotted*, areas of terrigenous deposits; *vertical ruling*, areas of Globigerina ooze and coral muds; *horizontal ruling*, areas of red muds; *horizontal broken lines*, areas of Diatom ooze. After Murray and Renard, modified from Kayser's *Allgemeine Geologie*.

mostly derived from the continents and is carried seaward by the action of the waves and the currents; while the impalpably fine oozes of the oceanic abysses are largely of organic origin and mainly result from the microscopic floating forms of plants and animals that live in the upper sunlit waters, and upon their death rain into the deeps, where their soft parts are food for the life of the bottom, and their skeletons go to make up the muds of the deep seas (see Figs., p. 115 of Pt. I, and pp. 68–70 of Pt. II). Wind-borne volcanic and desert dust and the disintegrated floating pumice are also contributed, however, and become notable in the composition of the red clays which floor the deepest parts of the ocean basins.

Globigerina Ooze. — Globigerina ooze is a fine organic mud with more than 30 per cent of calcium carbonate, derived in the main from the tests of the microscopic animals known as Foraminifera, of which *Globigerina* and *Orbulina* are the most prevalent forms (Fig., p. 68). These animals, of which there are about twenty kinds in tropical regions, live in the sunlit waters and after their death drop into the abyss. To them in the warmest waters are added other microscopic calcareous particles derived from lime-secreting algæ (coccospheres and rhabdospheres, Figs. 4–5, p. 154). This type of ooze is more widely distributed than any other, and usually occurs in depths of less than 15,000 feet and more than 6000 feet, although around tropical oceanic islands it may form in the shallowest of seas. On the one side the Globigerina ooze merges into the blue muds and on the other into the red clay, for at greater depths than 15,000 feet the solvent powers of the abyssal waters, as previously stated, dissolve the lime and carry it away in solution. The Globigerina oozes originate in the warmer waters and occupy nearly 30 per cent of the ocean bottoms (Fig., p. 71).

Diatom Ooze. — In the surface waters of the oceans also live microscopic plants that secrete beautifully ornamented siliceous tests, and of these a single species is particularly abundant in the polar waters (Fig., p. 69). Their tests after death fall into the deeps and there form the Diatom ooze, which occupies about 6.5 per cent of the oceans in high latitudes (Fig., p. 71). See also page 115 of Pt. I.

Radiolarian Ooze. — The Radiolaria are microscopic animals that also secrete very beautifully shaped and ornate tests of silica (Fig., p. 70); while they occur in all oceans they are most abundant and varied in the tropical regions of the Pacific and Indian oceans. The area of these oozes is small, being about 3.4 per cent of the oceans. Murray states that the Radiolarian ooze may be regarded as a variety of red clay containing many radiolarian skeletons (Fig., p. 71).

The Living Plankton. — The life feature of prime importance in the ocean is the *plankton*, a term that Haeckel proposed for the passively floating life of the seas, a world of little things, which is also a part of the *pelagic life*. It may be gathered in a very fine meshed net, and when so taken appears as a variously colored gelatinous film having a fishy smell. The great majority of the plankton is made up of primitive plants (mainly algæ, Fig., p. 69, and Figs. 4, 5, p. 154) and animals (chiefly Foraminifera and Radiolaria,

Figs., pp. 68 and 70, and, at certain seasons, the larvæ of higher animals) that are microscopic in size. It is a wonderfully interesting micro-flora and -fauna, a well adjusted society of organisms with its *producing class* of synthetic plant forms, and its *consuming class* of animals. It is self-sustaining and independent of the land other than for chemical and mineral foods. It has been described as "the pastures of the sea" and compared with "the grass of the fields." The quantity and variety change from place to place and with the season of the year, being far more abundant close to the lands and in temperate waters than out in the open ocean and in polar seas.

The plankton lives and propagates mainly in the upper 300 feet of the oceans. It is the cause of most of the phosphorescence seen glowing at night, for much of it then rises to the surface. "There is a cascade of sparks at the prow, a stream of sparks all along the water-level, a welter of sparks in the wake, and even where the waves break there is fire. So it goes on for miles and hours, and is just one of a thousand ways of feeling the abundance of life" (Thomson). The plankton is also the food for most of the animals living on the bottom of the oceans, which are collectively known as the *benthos*, and all animals that swim freely about are dependent for sustenance upon it. In other words, the plankton is the ultimate source of food for all marine animals.

The plankton directly figures but little in Geology because of its very perishable nature. Indirectly, it makes important contributions by adding carbon to the black muds.

Life of the Cold Abyssal Waters. — The waters at the bottom over the abyssal plains are everywhere dark, icy cold, and almost without movement. In addition, the pressure is great, the oxygen is scarce, and as there are no barriers the highly specialized animal life, in the main invertebrates, has migrated quite uniformly, though sparingly, over the bottoms. The sparse fauna consists mostly of blind forms, and where eyes have been inherited and are still functional, as in some fishes, they are enlarged to great size that they may catch any ray of light, for nearly all abyssal invertebrates and fishes are phosphorescent, thus being able to "transform the dark depths into a magic garden." In some of the fishes the entire body glows, in others there are rows of minute sparkling spots on the sides of the body, or there are flashing lights on the head, or at the ends of long tentacles. Others have long delicate feelers for finding their way along the bottoms of the dark abysses.

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CHAPTER VI

SEAS, THE ESSENTIAL RECORDERS OF EARTH HISTORY

Kinds of Seas. — In the previous chapter we saw that the ocean basins are more than full, and that the waters have spread over parts of the continents to a depth of about 600 feet, developing the shelf or marginal seas and the inland seas. In general use the word *sea* is interchangeable with ocean, but in Geology it is more often used in a restricted sense and in its original meaning. It appears to have originated with the peoples of northwestern Europe who were familiar with the North Sea and the East or Baltic Sea. These are marginal and inland bodies of marine water that in the main are under 200 feet in depth, and lie upon or within the continent; hence they contrast distinctly with the far deeper and larger mediterraneans and the abyssal oceans (Fig., p. 71).

The marginal or *shelf seas* lie upon the borders of the continental platforms, and the Germans often call them " flat seas " because of their shallowness and their flat bottoms. Examples are the North Sea, and the Yellow and Eastern seas of China.

Other shallow bodies of marine waters connected with the shelf seas or oceans, but situated wholly within the continental platforms, are in this book called *epeiric seas* (see Pt. I, page 111, and Pt. II, Fig., p. 77). Examples of these are Hudson Bay, the Gulf of St. Lawrence, and the Baltic Sea. In the geologic past all of the continents have been more or less widely flooded by overlaps of the oceans, all of which are thought to have been shallow and usually under 300 feet in depth, though in places they undoubtedly were deeper. Long ago Dana called these *continental interior seas* or *interior seas*, and his terms should have prevailed, but unfortunately the name "continental deposits" came to be applied later, not to the sediments of the shallow marine waters but to those of the fresh waters. As the term " continental deposits " in this sense is now ingrained in Geology, we can no longer use Dana's " continental seas," without raising a question in the mind as to what is meant when their deposits are considered. Hence we propose here to use the term epeiric seas (meaning seas that lie upon the continents) for the bodies of water that flood the interior of the continents. As a rule,

these waters do not have the normal salt content of oceans (3.5 per cent), but are more or less freshened. In arid places they are, however, far more saline and at times pass into salt-depositing seas. The areas of these seas have in times past experienced great changes through variations of sea-level, sometimes being more or less completely emptied of their water, or filled with sediments and turned into land.

Relic seas and lakes are great bodies of fresh, brackish, or even highly saline waters now completely cut off from the mediterraneans and oceans, but whose present life shows clearly that they were once in open connection with them. The best-known examples of these severed bodies of marine waters are the Caspian Sea and Lake Champlain (Fig., p. 77). These lakes are therefore marine relics of the past that have gradually been freshened through the inflow of rivers. In the same way we speak of *relic faunas* or *relic species*, meaning that they are relics which have adapted themselves to their present fresh-water or brackish-water habitats in these relic seas (see Pt. I, p. 80). The Great Lakes originated very recently, have always had fresh waters, and are dammed river valleys.

The Caspian Sea is the largest land-locked body of water, with an areal extent of 170,000 square miles. In the south it attains a depth of 3190 feet. It has now no outlet and its waters are removed by evaporation. Formerly it was a vast inland mediterranean with epeiric connections extending to the Arctic Ocean and the Roman mediterranean. The fauna is a deficient one, having marine fishes, porpoises, and seals.

The best demonstration that Lake Champlain is a relic sea is seen in its elevated beach deposits of very recent origin (Pleistocene), which have an abundance of marine shells and the bones of seals and whales.

Extent of Seas. — At present the shelf and epeiric seas occupy about 5.1 per cent of the earth's surface, or nearly 10,000,000 square miles, but in the past they were vastly greater, for the North American continent has several times been flooded by epeiric seas that covered from one third to about one half its areal extent. In fact, almost all of Stratigraphic Geology is a study of the sediments of epeiric seas, while it deals little with those of the shelf seas and scarcely at all with the ocean oozes.

Waves. — The surfaces of the oceans are never absolutely quiet, are usually least disturbed during calm rains, and are roughest when the winds are blowing strongly. "Wind is the mother of waves." Storms are cyclonic and rarely have diameters of more than 500 miles, so that the "fetch of the wind" may be blowing in one direction up to this distance. The longer the "fetch"

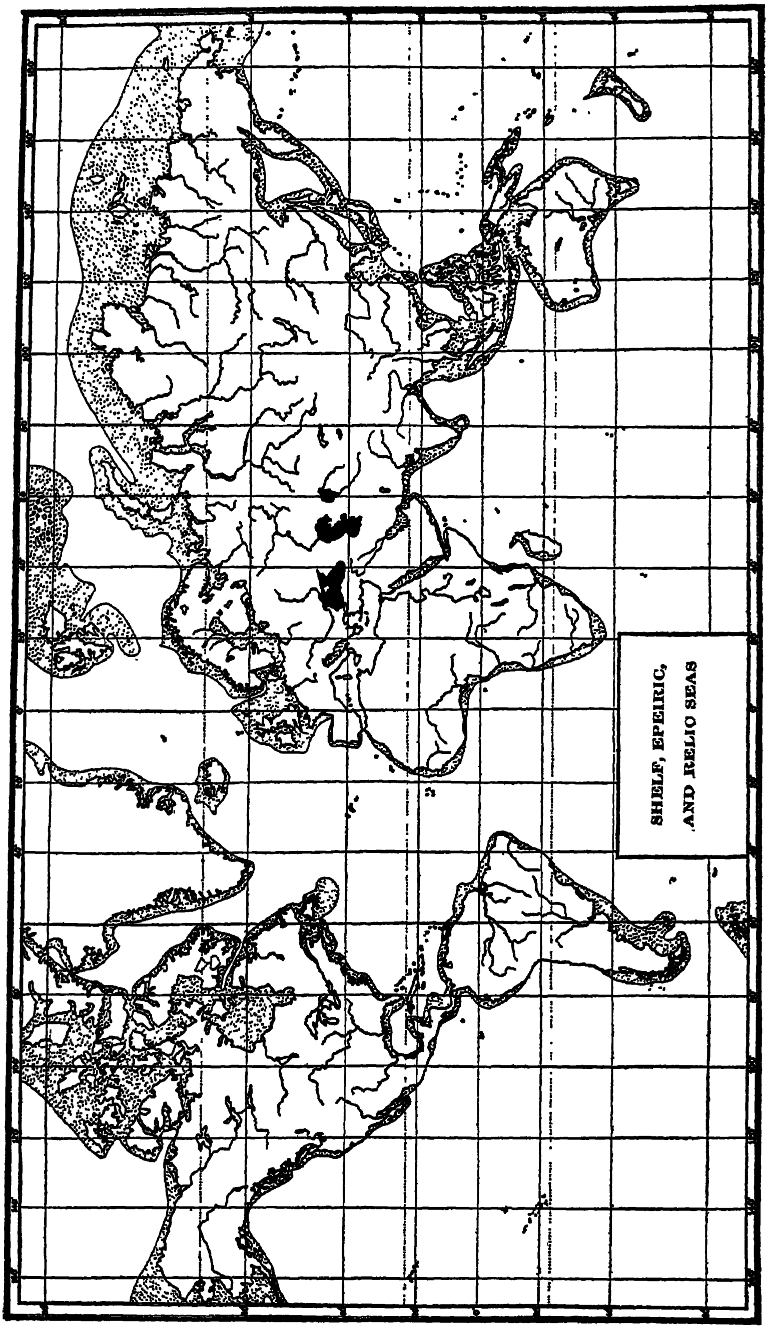

Fig. 23. — Lands (white), seas (dotted), and oceans (white). The areas of the shelf and epeiric seas are shaded in dots, and the largest relic seas are in solid black.

of strong winds, the higher the waves, that is, the friction of the wind upon the ocean surface pushes it into waves, the highest of which attain to 50 feet or more. Waves up to 40 feet high are of fairly frequent occurrence in the open ocean.

It is now certain that the waves of the greater storms in the oceans penetrate downward to at least 600 feet and in exceptional cases possibly even to 700 feet. Therefore even at these depths the muds may be stirred up and moved from place to place. At depths of 220 feet, gravel the size of hazelnuts is moved about, and stones weighing up to a pound have been drifted into lobster pots at a depth of 180 feet. Tidal and oceanic currents, moreover, penetrate to still greater depths, as stated in the previous chapter under currents.

Water waves are of two kinds, (1) *waves of oscillation*, and (2) *waves of translation*. The former are the ordinary waves of water bodies, and in them the fluid moves in circles, running not only in the direction of the wind, but downward as well, though losing strength with depth. The water on the crests of these waves moves forward, and that in the troughs backward, hence the term oscillation, because the water oscillates back and forth and does not run continuously forward. The waves of water in currents are those of translation, and here the motion is all forward as the waves pass, and there is no compensating backward motion.

Life of Shelf and Epeiric Seas. — The seas are wholly transparent to the sunlight (diaphanous); accordingly, they constitute the only marine area where the bottoms are more or less covered with ground-dwelling plants, and all animals that feed upon such plants are restricted to these waters. As the seas are adjacent to the lands, receive the rivers, and feel the full effect of the waves and tides, it is natural that they should vary greatly in temperature, salinity, bottom scour, and sedimentation. Since the oceans are mobile, any movement within the earth's mass is reflected by them and causes the seas to become shallower or deeper, or even to be transformed into dry land. Because of these constant changes in the physical, chemical, and organic environment, the epeiric and shelf seas are also the scene of severe struggles among their inhabitants and consequently are the principal arenas of marine biotic evolution. We may then say that the degree of intensity of all these interactions is most marked toward the land, and in the shelf seas diminishes away from it down the continental slopes.

The seas of the continental shelves are not only the regions of greatest abundance of marine bottom-living life, or benthos, as

previously stated, but also the ones from which all the other water bodies of the world have been colonized. Accordingly these regions are sometimes reférred to as the "cradle of evolution." Here is found the greatest abundance of life, and as well the most severe struggle for existence. Survival is far more difficult in these seas than in the open oceans. From the shallow-water seas bottom-living forms and swimming organisms have made their way into the abysses and others have voluntarily or involuntarily attained to a life in the inland lakes and rivers through modification of their habitats from salt to fresh waters, or, by changing water-breathing organs into lungs, have even become denizens of the dry land itself.

The largest quantity of shallow-water marine life is in the temperate waters, and the greatest number of kinds occurs in the warmer waters. Bottom-living plants, the seaweeds, are most prolific in waters down to about 400 feet, and none go much beyond 600 feet. This is the most striking difference between the life of the shallower waters and that of the oceans proper, for the animals of the deeper parts of the shelf seas continue down the continental slopes, and, even though in reduced quantity, they are still comparatively varied and abundant at depths of 9000 feet. Beyond this they diminish quickly and over the abyssal plains they are very scarce indeed, consisting only of forms highly modified to cope with the peculiarities of their environment.

The life habituated to shallow waters can, as a rule, spread only throughout the shallow seas and along the shelf seas bordering continents, never across the ocean bottoms. Nor can it spread directly across the ocean surface, and even when in the larval state as floaters there is not time enough for it to be conveyed across to the far away shelf seas. When the earth had mild climates, the conditions were favorable for slow continuous radiation into all seas, and it was at such times that the cosmopolitan faunas were developed.

Effect of Rivers on Sea-life. — Rivers enter the sea through estuaries or deltas, changing the waters from normal marine to brackish or more or less freshened ones. Here the environment of the rivers meets that of the seas, blotting out most of the marine organisms, and not only piling up the greatest depths of sediments, but also bringing about the most marked variations in sedimentation. Very little of marine life has ever been able to withstand the environment of rivers and so accommodate or permanently adapt itself to brackish and even less so to fresh water.

Divisions of the Seas

On the basis of their depth and the nature of their rock deposits, we may divide the seas into the strand, the shallow-water littoral, and the deep-water pelitic areas.

The Strand. — All students of the seas are agreed that the strand (the shore, beach, or foreshore) is the most easily defined region, since it lies between high and low tides. It has therefore also been called the *intertidal region.* In most places the strand is a narrow one, varying in width up to several hundred feet, but where the bordering lands are very flat it may attain a width of miles. Here the deposits are exceedingly variable in composition and usually coarse in grain, for it is naturally the region of most active wave force. Along the strand we may meet with cliffs, or rivers may bring in gravels, and from either source are formed conglomerates and coarse sands. Conglomerates, as a rule, are of continental origin, but those of the seas either occur at the base of formations, where they are made by waves beating against the cliffs, or are the interbedded gravel deposits brought by the rivers. Where the sea shades into the land may occur the finer sands or muds, which are often rippled, sun-cracked (Fig., p. 279), or trampled over by the land animals, frequently preserving their tracks (Fig., p. 473). It is very important to bear in mind that mud-cracking is practically restricted to the deposits of the strand and to continental formations (see Pt. I, p. 286), for these are the sediments that in the main are exposed to the air sufficiently long to be dried enough to bring about shrinking and tensional cracking. However, there are also areas of the strand, as in the present Runn of Cutch, India (8000 square miles), where marine *playas* (broad mud flats) are bared for months at a time from the sea. It is very probable that the sun-cracked Paleozoic water-limestones of the Appalachian region were formed in this way. This is also the region in which flat pebble limestone conglomerates are made.

The nature of the strand deposits is, however, dependent not only upon the topography of the land and the proximity of the rivers, but equally upon the climate and the waves and currents that are produced by the winds and tides. The winds constantly vary in intensity and shift in direction, and with them the waves and currents, bringing about, in the "sea mills" thus formed, a reduction in size of grain, an assorting of rock according to mass, shape (mica flakes), and specific gravity, and a drift of material now in this direction and now in another. However, the materials

of the strand are usually not in thick deposits and the marine conglomerates are as a rule under 10 feet, though they may attain locally to 100 feet.

Life of the Strand. — The strand is also the *amphibious region,* for sometimes it is a part of the dry land and again it is under the sea. For this reason its life is a peculiar one, highly adapted to an environment that is neither wholly of the one nor the other region; nevertheless most of the organisms are of the sea. When the tide is out they do not feed and most of them are buried in the wet ground, hidden beneath the rocks, under the seaweeds, or in pools of water. The kinds of animals that are peculiar to the strand are not many, for most of its dwellers are forms that also live in the adjacent region of permanent water.

The Littoral Seas. — Beyond the strand is the *littoral region.* Some use this term in place of strand, and still others include in it the entire depth of the seas. The Latin word, *litoralis,* means *belonging to the seashore,* and in this book we shall so use it, but continue the region from the lower limit of the strand to a depth of 250 feet, the latter point being chosen because at this depth *most* of the decided assorting power of the waves and their undertow ceases. The littoral region therefore merges landward into the strand and seaward into the deeper or pelitic waters. The waves of these shallow waters are most powerful and push the coarser material landward, piling it up toward the strand, while the finer substance is dragged seaward. The sediments, like those of the strand, are exceedingly variable, running from conglomerates to clean, coarse, shifting sands, dirty sands that consolidate and do not shift, and coarser muds. The offshore portions of delta deposits are also laid down in these depths and their shifting sands are dominantly rippled and occasionally much cross-bedded. These littoral deposits, due in the main to the inflowing of the rivers, are apt to have remains of land animals and more especially of land plants, such as leaves, stems, and wood, objects far less prevalent in the deeper water deposits. It should, however, be said that but little vegetable matter is entombed in the deposits of warm waters, for the great drifts of timber and other vascular or fibrous material are usually best preserved in temperate and colder waters.

As the storm waves act with some force to depths of about 250 feet, we see again why the littoral region is marked by conglomerates, by sands that are rippled and often more or less crossbedded, and by quick alternations of sands and muds, both vertically and horizontally; in a word, it is preëminently the region of hetero-

geneous deposits. The Dogger Bank of Great Britain lies from 40 to 90 feet beneath sea-level and is churned by the stormy waves, unearthing mastodon teeth which the fishermen bring up on their lines. Ripple-marks have been seen in depths of 50 feet, others are known on sandy bottoms sounded at depths of 600 feet, and fine sand has been thrown on the decks of ships where the waters were 150 feet deep. Therefore, great storm waves in their oscillatory motion lift and rework the littoral bottoms, break up the muds into tabular fragments or roll them into mud-balls, and in this way also make the well-known *intraformational conglomerates*, so called because the fragments of which they consist are of the same deposit and age as the rocks in which they lie, and are not of foreign rocks, as is the case with the ordinary type of conglomerates. Intraformational conglomerates made of flat thin pieces of limestones or dolomites are commonly formed in playa deposits when the sea returns over the areas of mud-cracked and hardened deposits, breaking them up and drifting the pieces into deeper water.

The littoral region is also marked by *banks*, those flat shallow-water areas far out from land, such as form the great fishing ground to the south of Newfoundland and to the east of the Maritime Provinces of Canada. These banks are due in the main either to marine planation, or to currents that have piled up sand and muds; it is, however, not only the currents that do this work, for sea-water also rapidly precipitates the muds brought into the sea by the rivers. Thus all the coarser terrigenous material is dropped in the littoral, and only the finest particles are carried by the lessened currents into deeper waters.

To the tropical waters of the littoral region are restricted the great coral reefs, and consequently, with the assistance of the lime-secreting seaweeds and the denitrifying bacteria, these and the adjacent deeper waters are the areas of greatest limestone making. Here also in the shallow waters are formed the calcareous oölite deposits. In the temperate and cooler waters the reef corals are absent, and even though calcareous algæ are present they are of other kinds which are far less effective as makers of limestone. In the same waters but in depths between 35 and 90 feet are found those green seaweeds with wide and fluted blades that are yards in length, known as Laminaria. Growing in great tangles they form miniature forests and are characteristic of the *Laminarian zone*.

It is a well-known fact that *pure sandstones are poor in fossils*, but, when mixed with clay and more especially when limy, do con-

tain them, sometimes in considerable abundance. This is because clean sands are laid down well within the zone of wave agitation, which not only washes out the mud and carries it farther oceanward, but also shifts the sand. Such places have no seaweeds living on the bottom, and are generally unfavorable habitats for life because of the shifting nature of the deposits and the grinding action of the sharp sands on the organisms. Further, the porous sands permit circulation and solution and have no diffused lime to protect the shells from such dissolving action. It is, therefore, in limy sediments that fossils are most abundant. The subject is referred to again later in this chapter (under diagenesis).

Deep-water Pelitic Region. — Beyond the littoral is the deep-water pelitic region, which includes all the waters of the continental shelves and the epeiric seas from about 250 to 600 feet. The word *pelite* is much used in the study of rocks (Petrology), and in the main refers to fine-grained mud rocks; in connection with the seas, therefore, the word is intended to have reference to the widely uniform and fine-grained character of the deposits of the deeper waters. To these depths the storm waves generated at the surface rarely attain with decided eroding power, sufficing only to stir the fine mud which is carried thus far from land, but in most places there is also some movement of the waters due to the tidal and oceanic currents. Here also the green seaweeds become less and less abundant with depth, while the brown and red algæ are generally the forms of the deeper waters. On protected coasts, however, the continental slope into the oceans begins at about 240 feet of depth, owing to the lessened wave action.

The deposits of the pelitic region are the well assorted and widely spread fine sands, and the sandy, clayey, and calcareous muds, along with greater accumulations of organic débris. It should, however, be understood by the student that sedimentation in the deep-water portion of the seas is dependent not only upon the currents, but also upon the height of the adjacent lands and the nature of their climate (whether warm or cold, dry or moist), upon whether the rocks are soft strata or hard crystallines, and upon whether the land is clothed with vegetation or is a desert. These general tendencies are further altered by the currents, so that locally even the pelitic waters have deposits that are characteristic of the littoral.

Origin of Concretions in Pelitic Waters. — Where cold and warm water currents impinge on one another they are shifted from time to time by strong winds, and in such regions it occasionally happens that the cold shore waters are blown far into the areas of deep water, killing off many of the warm-water animals.

Such an area occurs off the New England States, where in 1882 almost all of the fishes and other swimming animals were killed. The carcasses eventually fall to the bottom and form nuclei which in their decomposition set up the formation of concretions that are often phosphatic. Similar beds of concretions are also met with in the ancient deposits.

Stagnant Sea Areas. — In the shallow parts of the oceans and in all seas there are large and small areas where the waters are stagnant, and because of the lack of currents the animals living on the bottom, the benthos, soon consume all of the free oxygen that has been absorbed in the main from the atmosphere. Such bottom waters are said to be "stale," and they are taken possession of by sulphur-making bacteria which feed upon the micro-organisms and other life that fall from the sunlit, oxygen-absorbing surface zone. As the result of the bacterial life processes, the bottom waters become more and more foul through the liberation of sulphuretted hydrogen gas. Such bottoms deposit a very fine, black, ooze-like mud, on which but little life at best can maintain itself. The abundance of organic matter colors the muds blue-black to black and it abounds in petroleum and in sulphide metals, usually iron pyrite. Many formations of this kind are known in Geology, and some of them have a petroleum content as high as 20 per cent.

On the other hand, where the prevailing winds are strong toward the land, there is developed a marked seaward undertow that sweeps the bottom clean of deposits and of the organic products of decomposition from the abundant life of the littoral. The material gathers in the currentless depressions of the pelitic region, where it accumulates as black mud. Such *dead grounds* are known in many seas. Others, such as the submarine channel of the Hudson River, are known as *mud holes.*

Walther says that as long as a part of the seas is in open circulation with the ocean and its waters are constantly interchanged and the normal salinity maintained, there will live and be continued a normal marine fauna. As soon, however, as the free circulation of the water ceases, as in a quiet bay or between islands of an archipelago, all normal conditions are altered. Such stagnant places are characterized by accumulations of organic matter, by the development of poisonous sulphuretted hydrogen gas in the water, and by the vanishing of bottom-living organisms. Only the floating and swimming organisms or drifted plant material attain these quiet places, where they are often wonderfully conserved in the muds. This detailed preservation is well known in America, for in the black shales at Banff, Alberta, and Rome, New York, we have examples of trilobites retaining the antennæ and limbs in an extraordinary state of preservation.

Mud Bottoms. — As a rule the areas of mud accumulation are devoid of attached seaweeds and, since the water currents are here very slight, little food is brought to the animals that might

otherwise live upon or in the mud. In consequence the mud areas have a scant life and are known as the *desert areas of the seas*. These observations of the present marginal seas also help us to understand the dearth of life in the majority of the green, blue, and black shale deposits of epeiric origin. When fossils of bottom-dwelling types do occur, they are in thin zones and more often swimming or floating forms.

Sediments and Their Alteration

Kinds of Sediments. — In general it may be said that the sediments of seas are coarser in grain than the oceanic deposits, but of finer grain and far better assorted by the moving waters than the continental formations. The sediments of all strata are either *mechanically formed* or of *organic origin*. The former embrace the *arenaceous deposits* such as the sandstones and sandy shales, and the *argillaceous deposits* or mudstones, such as clay, shale, and slate. The *organic deposits* consist of limestone, dolomite, chalk, marl, and coal.

All of the sedimentary materials are derived in the first instance from igneous rocks (chiefly granites), and it has been calculated that such upon complete weathering should yield 80 per cent of mudstones, 15 per cent of sandstones, and 5 per cent of organic deposits (F. W. Clarke). These figures are, however, not borne out in the strata seen by geologists, for they average about 48 per cent of mudstones, 32 per cent of sandstones, and 20 per cent of organic deposits (Leith and Mead). These discrepancies are chiefly due (1) to the intermixtures of muds and sands, and mud and lime, as explained on p. 281 of Pt. I; (2) to the fact that the igneous rocks on weathering increase in volume at least 28 per cent; and (3) to the fact that considerable of the finest muds and much of the solution materials are permanently lost to the continents. What percentage of materials is thus transferred to the oceans is unknown, but it may amount to 25 per cent.

Deposition of Limestones and Dolomites. — The lime and magnesia carried in solution by the rivers to the seas are distributed far and wide by the marine currents. That small part which is taken out of the water through organic agency in the littoral is masked because of its dissemination through the thick deposits of these seas. For this reason it is usually said that limestones and dolomites are the deposits of the deeper waters and those far from the shore. However, back of the Keys of southern Florida, where the waters are warm and the land is limestone and but little above

sea-level, limestone and oölite deposits may be seen accumulating on the very shore. In the past few years it has become plain that the main areas of limestone and dolomite formation are the warm waters, for in the tropical regions not only do the rivers bring to the sea more lime, but the oceans are also far richer in denitrifying bacteria (Fig., below) and it is these micro-organisms that in their physiological processes throw down the main amount of lime carbonate. To this are added the structures made by the lime-secreting algæ, of which there are many kinds, by the coral reefs, and by other lime-using animals. The calcareous muds in the deeper water of tropical and subtropical regions, in depths of from 600 to 2000 feet or even more, have from 80 to 90 per cent of lime, and of this from 10 to 50 per cent originates in the floating Foraminifera, while from 2 to 40 per cent is from bottom-living Protozoa. Proceeding poleward we meet with less and less of limestone accumulation, though this is locally variable, dependent upon the temperature of the surface waters that again are so largely altered by the great oceanic currents.

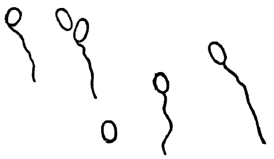

Fig. 24. — The bacteria that cause the precipitation of calcium carbonate in the ocean (*Pseudomonas calcis*). Greatly enlarged. After Kellerman and Smith.

Walther says the conversion of the sulphate of lime of the oceans into the calcium carbonate of the limestones by organisms is the greatest quantitative change wrought by life upon the face of the earth.

Nansen has directed attention to the hemipelagic muds of the central Arctic Ocean, which he says are devoid of large organisms and are brown in color, with only from 1 to 3 and rarely 5 per cent of lime. He states that this mud is a mineral deposit devoid of life other than a few bottom-dwelling Foraminifera. The muds of the Arctic waters off Europe show far more lime, from 25 to 40 per cent, with a maximum off Iceland of from 45 to 60 per cent, dropping at Jan Mayen again to 10 per cent. Most of this lime is from Foraminifera (*Biloculina*). It would further appear that more lime is present in the surface muds than in those beneath, an increase that may be due to the gradual warming of the climate in recent geologic time.

Diagenesis. — As limestones are of organic origin, naturally they should have an abundance of fossils, and most of them do. It is well known, however, that many are more or less crystalline, as are nearly all of the dolomites, and in this case fossils are usually absent or are so altered as to be almost unrecognizable. Here we are not dealing with metamorphism, because many such limestones and dolomites still remain horizontal and occur in areas unaffected by elevation and igneous injection. It is true that a process of alteration has taken place, but it was contemporaneous with accumulation and not ages afterward. The diagenetic changes are due to chemical alterations taking place on the sea bot-

tom and in warm waters. The Globigerina oozes of the present seas show no alterations and, even though they are the *growth* of warm surface waters, are accumulated in the ice-cold depths of the ocean abysses. The limestones of shallow warm waters, as for instance many coral reefs, have lost most of their organic structures, and we learn by careful study that the carbonate of lime originally present in the form of aragonite has been converted into calcite. In addition, the original carbonate of lime in either form may be more or less replaced by magnesium carbonate and thus a calcium carbonate coral reef, or a limestone of vast extent, may be altered into a dolomite. Time, warm and shallow water, variable concentration of solutions, much oxygen, and a wealth of decomposing organic matter are the requisites that will completely alter calcareous organic accumulations into crystalline limestones and dolomites before complete consolidation has taken place. This alteration has been called by Walther *diagenesis*, from words meaning *through* and *birth*, or, in other words, it is a rebirth through contemporaneous alteration.

Iron pyrite and marcasite concretions and fossils of black shales are also diagenetic products. Moreover, it has been held that the *flints* of chalk deposits are diagenetic in origin where the colloidal silica of sponges is progressively dissolved and redeposited about nuclei as flint and thus converted into these irregular lumps. On the other hand, the *cherts* of limestones develop near the surface in the zone of the circulating ground waters during the process of weathering, and are therefore not of diagenetic origin. As chalk is porous to ground water, and as the flints occur in both horizontal and vertical attitudes, it is probable that they, too, are formed after the sediments are uplifted sufficiently high to permit the circulation of meteoric waters.

Collateral Reading

VAUGHAN CORNISH, Waves of the Sea and Other Water-waves. Chicago (Open Court), 1910.

D. W. JOHNSON, Shore Processes and Shoreline Development. New York (Wiley), 1919.

J. WALTHER, Einleitung in die Geologie als Historische Wissenschaft. Jena (Fischer), 1894, Chapter 13, Die Diagenese.

CHAPTER VII

THE GEOLOGICAL TIME TABLE, AND THE AGE OF THE EARTH

Geology is one of the natural sciences, and among its various pursuits also seeks to unravel the history and age of the earth. "Speak to the earth and it shall teach thee," we read in the book of Job. "Go and see," is the first principle in Geology. The history of the earth has automatically recorded itself in the lithosphere, and it is this wonderful record that geologists seek to write down as Historical Geology.

With Lyell, we agree that "strata have been always forming somewhere, and therefore at every moment of past time Nature has added a page to her archives; but, in reference to this subject, it should be remembered that we can never hope to compile a consecutive history by gathering together monuments which were originally detached and scattered over the globe."

Rise of the Earth Sciences. — In ancient times, most of the philosophers of India, Egypt, Greece, and Rome failed to study the order in the lithosphere, and indulged in the more attractive but fruitless discussion concerning the origin of the earth and the great catastrophes to which it was supposed to have been subjected. Certain Arabian writers of the tenth century, and in the sixteenth to eighteenth centuries the philosophers of Italy and later of France, Germany, and England, laid the true foundation of a science of Geology. A marked advance came when they fully realized that the fossils in the earth's strata represented once living things, and that the earth is vastly older than some thousands of years. "It is very difficult at first sight," says Judd in *The Students' Lyell*, "to believe that the making of lofty mountains and deep valleys, the piling together of many thousands of feet of materials, and the passing away of whole generations of living creatures, have not been brought about by great and convulsive throes of nature rather than by simple causes operating through vast periods of time."

Geologic classification had its origin in the "formations" of two German geologists, Lehmann (1756) and Füchsel (1762). The older geologists had, in general, no clear ideas of the geographic

extent of geologic formations, but Abraham Gottlob Werner (1775–1817), professor of mining at Freiburg, Germany, had such a conception, and on the basis of some facts and much fancy he taught with wonderful success that the formations were universal for the earth, a fallacy of which Geology to this day has not completely divested itself.

Geology was at first a science of minerals and rocks, and it was not until the significance of fossils as determinants of age was first worked out in England by Smith (1799–1801), and still more clearly by Cuvier and Brongniart in France (1808–1811), that stratigraphy and geologic chronology had their beginning. Cuvier, and more especially D'Orbigny, taught that each formation contained its own *specially created* flora and fauna, and that each creation was in turn *destroyed by a general catastrophe.* Geologists were largely swayed by these ideas until the appearance of Darwin's famous book, *The Origin of Species,* — although Lyell (the great Uniformitarian) had long previously combated the theories of the catastrophists.

The principle of the uniform operation of Nature's laws (=uniformitarianism) is the guiding one, not only of organic evolution, but of Geology as well. It was widely promulgated by Lyell, who got it from the first great geologist, James Hutton of Scotland (1795). The principle of uniformity and continuity in Nature implies the improbability of violent catastrophism in either the lifeless or living worlds; it teaches that we must seek in the operation of Nature's present actions the explanation of her past acts. This is the *law of uniformity.*

The idea of catastrophism has now given way to the theory of local and general changes in the environment, changes that bring about small and great alterations in the plants and animals and in their local associations. We learn, therefore, that the primary basis for discerning the sequence of geologic events is the fossils entombed in the strata at the time of their formation. However, many rocks have no fossils, and in the earlier and longer portion of the earth's history the life then existent was so rarely preserved that other methods have had to be devised to unravel their sequence and genetic relation to one another. These various principles will be described later in this chapter, beginning with the criteria (standards of judgment) of the fossils and then proceeding with those of oceanic spread, erosion, and diastrophism.

Basis of Chronology. — The fundamental principle underlying all endeavor to make out the geologic past is *evolution,* the oscillating

but progressive changes wrought in the long ages, changes whose interpretation leads to the history of the earth — the science of Historical Geology.

The earth develops as a whole, but the record is far from being everywhere alike; even if it were so, it would not be wholly accessible for study, because sheet upon sheet of rock hides others below, and the atmospheric agencies have destroyed much through erosion. Likewise, the more complete stratigraphic record buried under the oceans is hopelessly inaccessible. Therefore the completed geologic record will eventually be put together from the evidence of all places which are at present land. Such history is largely brought about through the periodic adjustments of the lithosphere, which settles down upon a shrinking nucleus, and in so doing crushes the outer shell into great folds which tend to rise, especially toward the margins of the continents. Broad movements of a vertical nature also take place at times, whereby the continents tend to warp up and restore the elevations destroyed by erosion. On the other hand, the oceanic areas also move up and down, and as they are the reservoirs of all sediments derived from land wear, it is but natural that the marine waters should periodically flood the lands.

Time Terms in Geology

Geologic time is divided into eras, and these into periods that are composed of formations. It is therefore necessary to define these very far-reaching terms, since they will recur throughout the remainder of this book.

Eras. — An era is the longest division of time used in Geology; the eras are the volumes in the book of geologic time. They are comparable in human history to the Christian era, and like it, characterized by a striking change in events. The era terms are taken from the Greek language and are based on the state of organic evolution present. In the Paleozoic era, life is primitive (*palaios*, ancient, and *zoe*, life), and in the Cenozoic (*cainos*, recent) it is modern. We are living in the Psychozoic era, the era of reason.

A geologic era is composed of a group of periods. It is bounded by "critical periods," by the greatest of unconformities, and by the longest breaks in the geologic and organic records. At these times of emergence, the continents are largest and most protuberant above sea-level, and when the oceans again begin to spread over them, it is seen that the life has changed in the interval, the record of which is lost.

Near the close of the eras also occur the most extensive times of mountain making, and these elevations bring about marked changes in the environments that react strikingly on the life of the time. These times of major diastrophism are the *critical periods* or *revolutions* in the history of the earth, and they divide, as it were, the book of geologic time into chapters.

The critical periods are marked by the following features:

(1) By wide-spread deformation of the earth's crust, transmitted from place to place. This leads to the elevation of many and widely separated mountain ranges, followed by long intervals of erosion and mountain removal, and therefore by almost universal unconformities. Each revolution or critical period is named after one of the prominent mountain ranges formed at the time designated, for example, Laramide and Appalachian revolutions.

(2) By wide-spread changes in the physical geography. That is, there are at these times a highly diversified or young topography, decided alterations in the continental outlines, the making of new or the breaking down of old land connections (the land bridges which permit intercontinental organic migrations), and marked changes in the oceanic currents, all of which also lead to marked variations of temperature and often to actual glacial periods.

(3) By marked and wide-spread destruction of the previously dominant, prosperous, and highly specialized organic types.

(4) By the marked evolution of new dominant organic types out of the small-sized and less specialized stocks, and by the development of hordes of new species.

The last or Cascadian Revolution is so recent that the record of it is not lost, and a study of this enables us better to comprehend the changes wrought by the earlier revolutions. LeConte regards it "as the type, as the best proof of the fact of critical periods, and as throwing abundant light on the true character of such periods, and especially on the causes of the enormous changes in organic forms during such times."

The eras are divisible into *suberas* (the "major divisions" of the table, page 101) on the basis of physical changes and the dominance of a group of organisms. For instance, in the early Paleozoic subera there are practically no land plants or backboned animals, in the middle division land floras appear and fishes are common, while in the youngest division appear the land-living vertebrates.

Periods or Systems. — The eras and suberas are composed of periods of time or systems of rocks and they are the chapters in the book of geologic time. The older geologists based these on unconformities or marked differences in the entombed fossils. As the work proceeded, however, and knowledge became more detailed, it grew increasingly difficult to formulate principles for the discrimination of natural periods and systems.

In one form or another, geologists have always delimited their geologic divisions according to movements of the earth's crust,

but how to discriminate the smaller movements from those that have more or less of a world-wide application for the delimitation of periods or systems is only now becoming clearer. Dependence will always have to be placed primarily on the fossils, but some criterion besides that of the contained life is needed to differentiate between the systems of stratified rocks. Such a physical principle apparently exists in the periodic submergences of the continents, also known as the positive changes of sea-level, for when one of the floods attains its maximum of spread, the widest distribution of similar faunas and identical species would naturally be expected. Conversely, the maximum of continental emergence must mark the absence of marine faunas in most land areas, followed for a time by more or less dissimilar faunas in all the provinces. The plotting of these periodic submergences and emergences on paleogeographic maps, not merely for one continent but for most of the world, will make it possible to define the boundaries of the systems of rocks and will also help greatly to determine a more accurate time valuation of the formations and their life in the various continents. It is, therefore, the principles of *diastrophism*, *paleogeography*, and *organic evolution* that will eventually correctly define the periods or systems.

A period of time, according to H. S. Williams, is based on a sequence of "rock formations whose stratigraphic order and lithologic composition are thoroughly well expressed in some definable geographic region, and whose fossils indicate a more or less continuous biologic sequence." Hence their names are taken from the geographic area where they are first studied, e.g., Pennsylvanian, from the greatest coal state. The Cambrian, Silurian, and Devonian systems were first discriminated in England and Wales, and take their names from ancient peoples living in these countries, or from the district in which the rocks are best developed. Triassic has reference to the tripartite development of rocks of that age in Germany, and is an heirloom from the days of Geology when the science had not worked out the principle that formations and periods must be based upon type areas. Cretaceous is a still older inheritance from the days of mineral Geology, the name being based upon the chalk deposits of western Europe.

The Three-fold Nature of Periods. — A period usually begins with highlands that are inherited from the previous period. There is therefore also marked erosion, and the limited sea-ways have dissimilar faunas. During the middle part of the periods, the oceanic transgressions are greatest, the lands are lowest, and the faunas

throughout a continent are most alike in composition and have the greatest number of species in common, that is, are "cosmopolitan faunas." Restriction again takes place during the closing part of the periods, though at these times there are many more hold-over species from the earlier, widely dispersed faunas; in other words, there is no marked introduction of new organic types during the recession of the seas. However, before the oceans again spread over the continents, a long time will have elapsed, many of the old familiar forms will have disappeared under the stress of restricted habitat, and new forms will have been developed, the prophets of a new period and indicative of the next trend in evolution.

Epochs and Series. — A period of time is very long, and a system of formations is usually of great thickness; in fact, these divisions embrace so many events that other and smaller groupings are required for their better comprehension. A period is therefore subdivided into *epochs* of time, and a system of formations is distributed into *series* of strata. In general, epochs and series are now rather arbitrary divisions established either on faunal grounds or on a long series of strata supposed to represent a sedimentary cycle, beginning in a conglomerate or sandstone and ending in calcareous deposits. While these criteria are more or less correct, they need to be checked by diastrophism and paleogeography. The epochs and series are further divided into *ages* (time) and *stages* (rocks), but these divisions have as yet no scientific precision.

Formations. — The epochs are again divided into formations. The word formation is in general practice used for the smallest units that can be plotted on a geologic map, and may embrace a single more or less thick succession of like sediments, such as the Trenton limestone, Rochester shale, or Medina sandstone, or a succession or alternation of sediments that are unlike (for example, shale, limestone, and sandstone), but have closely related faunas, such as the Hamilton formation. In short, any set of conformable strata that are without significant time breaks and are grouped together for any stratigraphic or faunal reason or a number of reasons may be termed a formation.

Disturbances. — As the eras end in revolutions, so the periods may terminate in crustal movements, and these times of diastrophism are known as disturbances, a term used by H. D. Rogers as long ago as 1856. It seems probable that the periods were all separated by disturbances, events occurring now in this and now in that continent.

Evidence of Fossils

Fossils furnish the first step in the process of stratigraphic correlation. Their testimony is checked by the geographic distribution of the sediments that contain them, and by the relation of the latter to the formations beneath and above them (superposition). These principles are easy to state but very difficult to apply accurately to so great a land mass as North America, and even though approximately a century of work has been devoted to it, the ground is only about half covered by detailed studies.

Changing Environment. — In general, sedimentation is a slow process, and under relatively constant surroundings, it is held that but little if any recognizable change in the species is developed, but as the environment of the organisms is continually changing, even though only to a minor extent, these physical alterations cause the life assemblages at the very least to alter their combinations and to shift from place to place. They die out in one area, but gain a foothold elsewhere, and although this to-and-fro migration is slow when measured in years, yet in stratigraphy the life assemblages appear as if suddenly introduced. This fact has always excited the interest of the paleontologist, and he has explained the phenomenon according to the view of his generation. Once he thought it due to special creations of new types or recoinages of old, but since the time of Darwin it has been looked upon as due to slow evolutions of which glimpses only are obtained in the fragments of the geologic record; or it may be due to shiftings of faunas, or to geologically sudden migrations into the continental or interior seas from the permanent or outer oceanic reservoirs, the continuous realms of marine organic evolution. The fossil faunas from the oceans spread as fast as the sea transgressed the land, and, for practical purposes in stratigraphy, they may be accepted as having appeared simultaneously in widely separated places.

Different Values of Different Fossils. — The localized species (forms restricted to a locality) are of the greatest value in the stratigraphy of small areas, while the new forms which attain wide dispersal are on the other hand of most significance in correlating the time stages in separated regions, for they are progressives, the time heralders, as distinguished from their variously conservative associates. Therefore in the chronologic correlation of the stratified rocks most dependence is put upon a few species, known as "guide fossils," together with the collateral evidence of associated forms.

Dissimilarity of Successive Faunas. — Locally successive marine faunas *derived from the same oceanic realm* usually exhibit a more or less ancestral or direct genetic relationship to one another. In some cases they are the returning, slightly altered descendants of an older fauna, in other words, "recurrent faunas." Therefore the possibility of a "break" in sedimentation between the strata containing such successive faunas is easily overlooked and the time value of the recurrent faunas underestimated. Or, two locally superposed faunas may be totally dissimilar, not only in the species but even in the majority of the genera, and yet the time break between them may be a comparatively short one, the reason for this unlikeness being that the two faunas are *migrations from different oceanic realms* and have therefore had a development from different ancestors.

Physical Evidence

Evidence of Periodic Oceanic Spreading. — Another primary principle of value in marking the periods of geologic chronology is the recognition of the times when the surface of the earth and the oceanic level are in decided motion. The crustal oscillations of the earth are not due to heterogeneous and unrelated movements, but are connected, in that areas of elevation and depression remain as such throughout the eras, or during more or less long stretches of geologic time. It is now clear that North America has been more or less widely flooded by the oceans at least fifteen times since the Proterozoic era, and that the other continents have been similarly flooded many times. The movement of the ocean waters may be of small and narrow extent, due to warpings of the lithosphere, or may spread over areas of great magnitude. As the lands are known to warp up and down and to fold into mountain ranges, it is but natural to conclude that the oceanic bottoms are affected in the same way. Not only do the lands move up and down, the sum of this motion being in the main upward (positive movements, called *geocratic* by Stefanini in 1917), but it is also now clear that the ocean bottoms are periodically more or less in motion, with the sum of their movements downward (negative movements, called *thalassocratic* by Stefanini). For these reasons, the oceanic level in relation to the continents is inconstant, and therefore the marine spreadings over the lands, with their concomitant sedimentation, are variable not only in time, but also in geographic extent. On the other hand, when the lands protrude more than usual above the strand-line, the oceans naturally overlap the continents least

widely and make at such times limited marine stratigraphic records, which are restricted to the margins and their embayments and to the persistent axes of depressions, the geosynclines of the continents (see Chapter X). As the oceans and seas are all connected one with another, and are also the receivers of most of the land wash or detritus, it follows that a displacement of the strand-line anywhere, through any cause, must be transmitted to all marine waters. It has been calculated that if the present protuberant land masses were transferred to the oceans, the general sea-level would be raised about 650 feet, and therefore the North American continent would be flooded to a depth of at least 200 feet. Then under the waters there is continuous sedimentation, and they abound in more or less of evolving life that is most advantageously situated for burial and preservation; hence the marine stratigraphic sequence is the least broken of the several kinds of historic records accessible to geologists.

As already stated, the amount of water in the oceans is fifteen times greater than the mass of land above sea-level. This is because the oceans have an average depth of 12,000 feet and cover about 70 per cent of the earth's surface, while the average elevation of all the lands is only 2250 feet and they occupy but 30 per cent of the lithosphere.

It is now known that the oceans have spread periodically and more or less widely over the North American continent, the areal extent of which is about 8,300,000 square miles. These floods occurred hardly at all during the Cenozoic; four times widely during the Mesozoic; and, with the maximum spread, apparently twelve times during the Paleozoic. More broadly it may be stated that the floods begin and end with shelf seas marginal to the continent and occupying between 1 per cent and 5 per cent of the total areas of the continental platform, the conditions being thus not unlike the present conditions of overlap; while the greatest inundations are of the interior or epeiric seas that during the middle of the periods cover from 12 per cent to 47 per cent of the continent.

It is therefore apparent why the major portion of the earth's chronology depends for its determination upon the marine sediments. These formations, except in so far as they are later eroded, record the extent of the transgressions, and, in their physical characters, something of the topographic form of the adjacent lands, with a hint as well of their climates; and through their fossils they establish the chronology from place to place.

There is a certain amount of *rhythm* in these periodic movements and this meter permits us to group the formations into systems or

periods. As has been shown, the periods usually begin with highlands inherited from the closing orogenic movements of the previous period. In contrast, the quieter but broader deformations within the period, of epeirogenic nature, as shown by the world-wide movements of the strand-lines (eustatic levels), are of long continuance. Each submergence with the following emergence is seemingly the natural basis for the delimiting of a period.

Evidence of Erosion. — Geologic chronology has been so far almost wholly, though necessarily, interpreted on the basis of stratified rock accumulations, that is, the marine and continental strata. There is, however, still another record that has so far been almost refused recognition in our time-tables. This is the time evaluation of topographic form at any given stage of development (the physiography of the present, the paleophysiography of the past). To be sure, it is mainly a condition of removal by erosion of previously made histories, but nevertheless the topographic form of the land still remains and has a time value. We all appreciate to a certain extent the significance of unconformities as records of emergence and erosion between periods of inundation, but can any one tell what time value is to be accorded to the complete removal to sea-level of mountain ranges like the present Alps of southern Europe? Many times have similar mountain chains been washed away and then again and again vertically reëlevated, only to be worn away after each reëlevation.

Evidence of Breaks. — The erosion intervals are the "breaks," the "lost intervals," or the disconformities and diastems (or diastemata) in the succession of strata. In addition to the disconformities, there are unconformities due to movements in the shell of the earth when mountains are made (see Pt. I, p. 306, *et seq.*).

The breaks are known to be many, but they are far greater in number, and their time durations, although admittedly very variable, are far longer than is usually believed to be the case (see Fig., p. 98). The geologic column will probably never be completed on the basis of the recoverable physical and organic evidence, but it will grow into greater perfection for a long time, and this growth will come through the discovery of formation after formation along the lines of these breaks, and more particularly in the areas nearest the continental margins. The perfection of the column will also bring about a greater harmony in the very variable estimates as to the age of the earth, as given on the one hand by the geologists and on the other by the physicists.

The major breaks in the geologic record are indicated in the time-table by "intervals," the marked erosion periods representative in the main of wide and high continents and of dominant erosion, not recorded by sediments within reach of observation; therefore, in geologic chronology these are "lost times" of long duration. It was not thought desirable to give a new and independent name to each one of these intervals, but rather to use in modified form an old and familiar one. Therefore the Greek word *epi* (upon or after) is here adopted as a prefix to the era terms, to indicate the subsequent time, that is, the intervals. These intervals will then be known as *Epi-Mesozoic, Epi-Paleozoic, Epi-Proterozoic, Ep-Algoman* and *Ep-Archeozoic.* This method of naming was first proposed

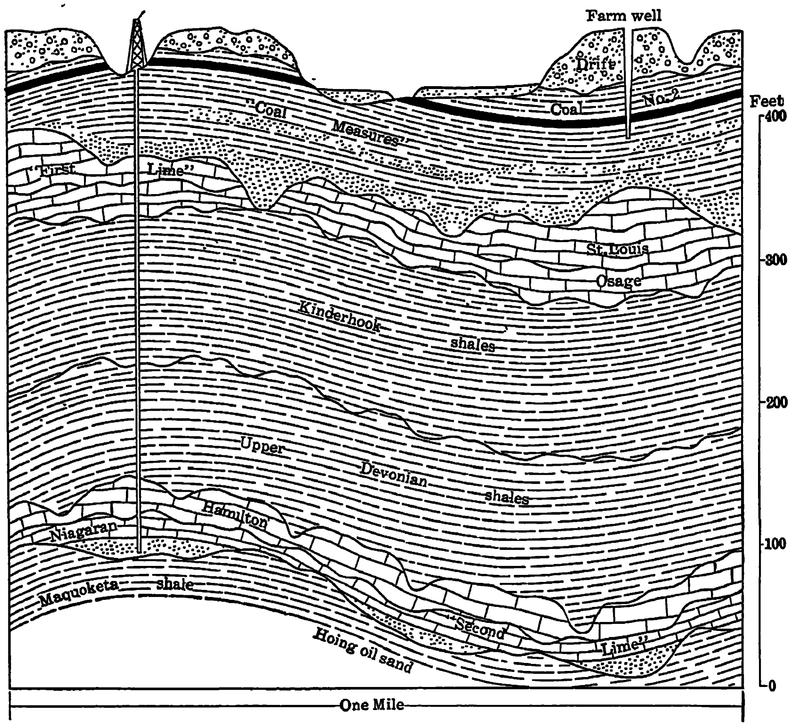

Fig. 25. — Diagram showing eight breaks in a depth of about 400 feet of Paleozoic strata, and in a length of one mile, in the Avon-Canton area of Illinois. After Savage.

by Lawson. The same combination can be used, when it becomes necessary, for the intervals between the periods, as *Epi-Silurian*, etc.

Diastrophism. — As shifting of the strand-line is the most important criterion in ascertaining diastrophic action (a term to include all movements of the outer parts of the earth, described at length in Chapter IX of Pt. I), it is well to state here briefly how these alterations are most readily determined. Organically they are recorded: (1) by abrupt changes in the superposed faunas, and (2) by the sudden appearance of newly evolved stocks; physically, (3) by more or less obvious breaks in the sedimentation, due to sea withdrawal, (4) by change in the character of the deposits, especially when this involves abrupt transition

from organically formed strata (marl, chalk, limestone, dolomite) to mudstone and sandstone, or a change from continental to marine deposition, and (5) by marine overlaps upon rocks of earlier age, producing typical unconformities.

Correlation of formations in separated regions is made in part also on a physical basis. This is done by finding similarities in disconformities (time breaks in conformably superposed or parallel strata, see Pt. I, p. 311, and Fig., p. 183), and changing petrologic characters. A physical correlation is in general, however, far less reliable, and must ever remain second in importance to correlation by fossils for the discernment of diastrophic action. Of course, the most easily determined crustal movements are those which are compressive in character and lead to mountain-folding. Upon erosion and subsequent sea invasion, these angular or structural unconformities are the most easily found and those about which there can be the least doubt. The broad and gentle flexures known as crustal warpings, on the contrary, as a rule bring about the disconformities.

The Geologic Time-table

The time is not yet at hand for a complete evaluation of the minor diastrophic movements, the disturbances, because the recorded geologic succession in the different countries is by no means the same. Hence it can not be stated that the periods in the accompanying table are the only ones that will eventually be recognized. It may truthfully be said, however, that there is now a good deal of harmony among geologists in their use of the theory that the surface of the earth is periodically and rhythmically in motion, and that this diastrophic action is the basis of chronogenesis, developing not only cycles of sea invasion and land emergence, and cycles of erosion, but also cycles of organic evolution. This cyclic condition is due to the revolving of the earth on its axis and about the sun, and of the latter in the universe. Although the eras are clearly recognizable everywhere, nevertheless, until the paleogeography of Europe is worked out in detail, we shall not be able to say that the various *periods* in current use are all established in nature.

The student is urged to commit to memory at least all of the names of the eras and periods and what is said of the life in the following tables. *This knowledge is the A, B, C of Historical Geology, and without it further progress is almost impossible.*

Geologic Chronology for North America

Eras are distinguished by world-wide revolutions and marked organic change. Periods are separated by crustal disturbances and moderate changes in life.

I. CLASSIFICATION BASED ON ORGANIC EVOLUTION, SUPERPOSITION OF STRATA, AND UNCONFORMITIES

Eras	Major Divisions	Periods	Epochs		Advances in Life	Dominant Life
Psychozoic	Recent or post-Glacial time			Cascadian Revolution	Rise of civilization Era of mental dominance	Age of Man
Cenozoic (Modern Life)	Late Cenozoic (Neogene)		Pleistocene or Glacial		Periodic glaciation Extinction of great mammals Dawn of reason, art, industry	Age of Mammals and Flowering Plants
			Pliocene		Man-ape changing into man	
			Miocene		Culmination of mammals	
	Early Cenozoic (Paleogene)		Oligocene		Rise of higher mammals, primates, and modern birds	
			Eocene		Vanishing of archaic mammals	
Mesozoic (Medieval Life)	Epi-Mesozoic interval			Laramide Revolution	Rise of archaic mammals	Age of Reptiles
	Late Mesozoic	Upper Cretaceous	Fort Union Lance		Extinction of dinosaurs	
			Montanian		Extreme specialization of reptiles	
			Coloradian			
		Lower Cretaceous			Rise of flowering plants	
	Early Mesozoic	Jurassic			Rise of toothed birds and flying reptiles	Age of Reptiles and Medieval Floras
		Triassic			Rise of dinosaurs and reptilian mammals	

Geologic Chronology for North America (*continued*)

Eras	Major Divisions	Periods	Epochs	Advances in Life	Dominant Life
Paleozoic (Ancient Life)	Late Paleozoic or Carboniferous	Epi-Paleozoic interval	Appalachian Revolution	Extinction of ancient life	Age of Amphibians and Ancient Floras
		Permian	Break Guadalupian Hueconian	Rise of land vertebrates, modern insects, and ammonites Periodic glaciation	
		Pennsylvanian	Monongahelan Conemaughan Alleghenian Pottsvillian	Rise of primitive reptiles and insects	
	Middle Paleozoic	Mississippian	Tennesseian	Rise of ancient sharks	Age of Fishes
			Waverlian	Maximum of crinids	
		Devonian	Upper Middle Lower	Rise of amphibians, marine fishes, goniatites Maximum of corals and brachiopods First land floras	
	Early Paleozoic	Silurian	Cayugan Niagaran Alexandrian	Rise of lung-fishes and scorpions	Age of Invertebrates
		Champlainian	Upper Middle Lower	Rise of land plants and corals Rise of armored fishes and bryozoans Rise of shelled animals	
		Cambrian	Ozarkian Croixian Acadian Taconian	Rise of cephalopods Dominance of trilobites First known marine faunas	

Geologic Chronology for North America (*continued*)

Archean or Pre-Cambrian of Older Authors
Mainly for Lakes Superior and Huron, and Ontario Province

II. Classification Based on Rock Sequence and Crustal Movements
Correlation without aid of fossils

<table>
<tr><td colspan="6">Epi-Proterozoic or Lipalian Interval and peneplanation of continents</td></tr>
<tr><th>Eras</th><th colspan="2">General Terms for Major Divisions</th><th>Lake Superior, after Leith</th><th>Lake Huron-Michipicoten, after Leith</th><th></th></tr>
<tr><td rowspan="9">Proterozoic</td><td rowspan="5">Algonkian</td><td>Killarney Revolution</td><td>Keweenawan granite</td><td>Killarnean granite</td><td rowspan="9">Age of Primitive Invertebrates
Great Iron Age. Rocks not much altered</td></tr>
<tr><td rowspan="2">Keweenawan series or Late Proterozoic | Beltian series of Rocky Mts.</td><td>Keweenawan formations</td><td>Keweenawan (norites)</td></tr>
<tr><td>Animikian or Upper Huronian</td><td>Whitewater</td></tr>
<tr><td rowspan="2">Huronian series or Middle Proterozoic</td><td>Middle Huronian</td><td>Cobalt and oldest known tillite</td></tr>
<tr><td>Lower Huronian</td><td>Bruce</td></tr>
<tr><td colspan="2">Ep-Algoman Interval</td><td></td><td></td></tr>
<tr><td rowspan="2">Timiskamian</td><td>Algoman Revolution</td><td>Giant's Range granite</td><td>Post-Doréan granite</td></tr>
<tr><td>Sudburian-Doréan* series or Early Proterozoic</td><td>Stuntz*-Ogishke conglomerate, Knife Lake slates</td><td>Doréan* sediments and volcanics</td></tr>
<tr><td colspan="4">* The pre-Huronian position of these formations is not yet definitely established, according to Leith.</td></tr>
<tr><td colspan="6">Ep-Archeozoic Interval and peneplanation of continents</td></tr>
<tr><td rowspan="2">Archeozoic or Archean</td><td rowspan="2">Loganian</td><td>Laurentian Revolution</td><td>Laurentian granite</td><td>Pre-Doréan granite</td><td rowspan="2">Age of Larval Life
Rocks greatly altered</td></tr>
<tr><td>Keewatin-Coutchiching series | ?Grenville series of Ontario (May not be Archeozoic)</td><td>Keewatin-Coutchiching</td><td>Pre-Doréan volcanics and sediments</td></tr>
</table>

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA (*continued*)

The Formative Eras of the Earth (After Barrell)

III. CLASSIFICATION HYPOTHETIC. NO KNOWN ROCK RECORD

Times	Divisions	Physical Characters
Eozoic	Dawn of Unicellular Life	Rocks probably similar to those of early Archeozoic time. Life changing the primal atmosphere
Azoic (Lifeless)	Initial Hydrospheric Time (Oceanic Era of Dana)	Time of most marked igneous activity Origin of water and a thin atmosphere
	Initial Lithospheric Time (Lithic Era of Dana)	Formation of a stable, cold, exterior shell Birth of oceanic depressions and continental platforms Centrosphere probably rigid
	Pyrospheric Time (Astral Eon of Dana)	Molten exterior. Earth evolving toward a rigid spheroid with a semi-solid exterior and a heavy atmosphere

Cosmic or Astronomic Time

Times	Divisions	Physical Characters
Cosmic	Time of Planetary and Lunar Growth	Rapid growth of the various dominant planetary nuclei through attraction of the planetoids and planetesimals that composed the solar disrupted material
	Time of Solar Nebula	Tidal disruption of ancestral sun and origin of planetary material

The Age of the Earth

To measure the duration of geologic time became a definite scientific aspiration during the past century. Many of the cosmogonists and even some of the geologists of the nineteenth century held to the biblical interpretation that the earth was created 4004 years B.C. This was Bishop Ussher's estimate in 1650, his interpretation of the "In the beginning" of Genesis, despite the fact that some of the ancient religions held that humanity had lived during many cycles, each of untold millenniums. Hutton in his studies of Scotch geology (1795) found "no vestige of a beginning — no prospect of an end." In 1860, John Phillips placed the age of the earth at 38,000,000 to 96,000,000 years, and geologists twenty years ago quite generally accepted 100,000,000 years as the probable

age since the beginning of Archeozoic time. Then in 1903 came the epochal discovery of radium and the knowledge that some of the so called elements break up into others. Shortly thereafter the physicists told the geologists that they must multiply their figure at least ten times! Truly there is now an embarrassing richness of time.

The different methods by which the age of the earth has been calculated are all based on a common principle. "The rates of certain changes at the present day are determined as accurately as possible, and in imagination, the respective processes are traced backward in time, until limiting conditions are arrived at. Thus Kelvin takes us back to a time when the earth was not yet a solid globe; [George] Darwin traces back the moon's history until he finds it revolving close to the earth; Joly bids us imagine the oceans in their original freshness, free, or nearly so, from salt; Geikie finds an end at last to the long succession of stratified rocks and seeks to estimate the time they represent. Last of all, and most brimful of promise, there lies in the mechanism of radioactivity an elegant method for assigning a date to the period of crystallization of every igneous rock in which suitable minerals can be found" (Holmes).

The two chief methods of Geology used in determining the age of the earth are (1) the rate of land denudation, or the rate of deposition of the sedimentary record, and (2) the rate of sodium chloride derivation from the land and its accumulation in the oceans.

The rates of denudation for nine large rivers are so discordant that they can not "afford any information of quantitative value" (Harker). In the Irawadi basin of India it is 1 foot in 400 years, and in the Hudson Bay region 1 foot in 47,000 years. For solvent denudation it is 1 foot in 30,000 years, and for mechanical removal 1 foot in 12,000 years. The known sedimentary record in its areas of thickest deposits now attains to something like 70 miles in depth. Such a mass of material means the wearing away to sea-level, one after another, of more than twenty ranges of mountains like the present European Alps or the American Rockies. On the other side of this picture of denudation are the long intermediate times of repose, when all the base-levelled lands furnished almost no sediments to the seas and oceans.

The physicist's "radioactive clock" obtains figures of the order of 1,600,000,000 years since early in the Archeozoic, while the leading geologists would nowadays admit on the basis of their hourglass that the sedimentary and saline records indicate a time of the order of, say, 250,000,000 to 300,000,000 years. This acceptable esti-

mate does not, however, take into consideration the uncountable breaks, i.e., the smaller number of very long-enduring angular unconformities, the great number of disconformities, and the exceedingly numerous diastemata. T. M. Reade estimated on the basis of limestone as an index of geological time that the age of the earth is "at least 600,000,000 years." Geology can therefore say

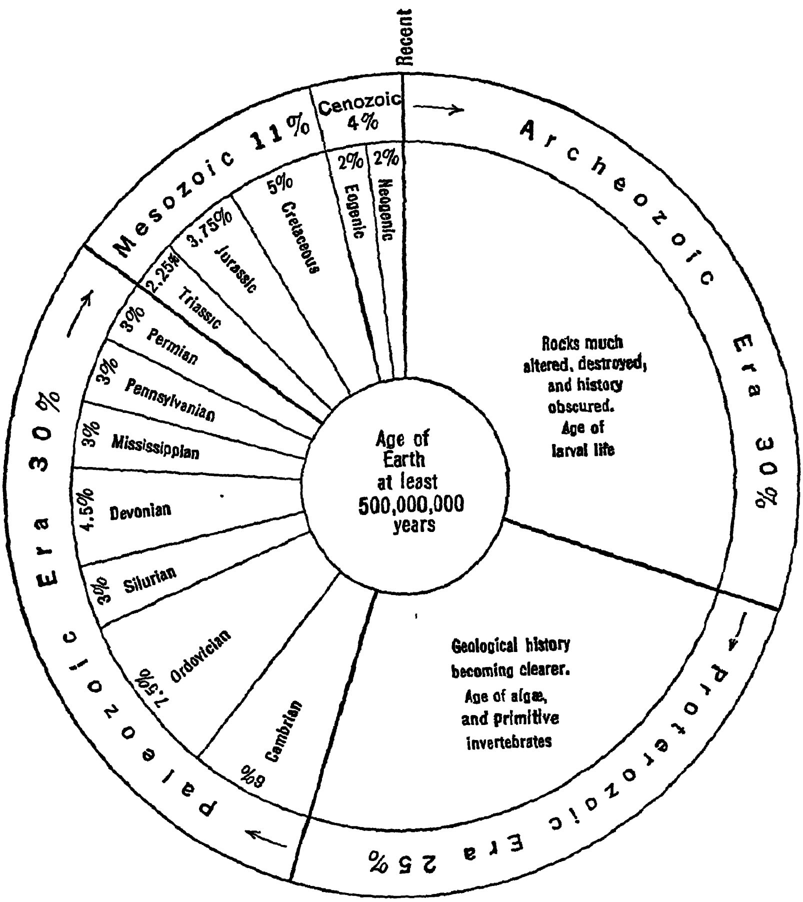

Fig. 26. — The geologic time table arranged in the form of a clock dial, with the duration of each time division given as a percentage of the whole.

that the earth since the beginning of the Archeozoic is probably at least 500,000,000 years old. On this basis the geologic "time clock" has been adjusted in the figure above.

It appears probable that the "radioactive clock" has not always been running at the present rate of disintegration, a view stoutly backed by Joly. The latter in 1923 still holds to an age of about 130,000,000 years, basing his conclusion

on thorium disintegration and not on that of uranium. On the other hand, it is also probable that the reading of the hourglass of denudation by the geologists is not wholly dependable; in fact, it is admitted that geologic time is longer than the readings indicate. Of the two calculations, however, the radioactive basis is the more dependable.

Any one wishing to be visually impressed with the immensity of geologic time should stand on the brink of the Grand Canyon in Arizona and reflect on how long it has taken the Colorado River to cut this nearly mile-deep gorge, the most beautiful and impressive in the world. He should also think of how long it has taken the seas to lay down this depth of Paleozoic strata and the more than two miles of Proterozoic sediments beneath them. Having done all this, he should remind himself that after all he has seen but a small part of the whole geologic column.

Still standing on the brink of the Grand Canyon, on a clear night he should turn his eyes skyward and note the many stars. All are exceedingly far away. Shapley tells us that one of the star clusters is 220,000 light-years away, and light travels at the rate of 186,000 miles per second.

With these statements we leave the subject of the age of the earth and take comfort in the knowledge that during all this time the sun has been radiating energy into space at about the same rate as it does now. The life of the Archeozoic basked in the warmth of the sun with the same comfort that the lilies and roses, or sequoia and man, do now.

Truly it is all beyond human comprehension!

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CHAPTER VIII

THE EVOLUTION OF THE STARS AND THE ORIGIN OF THE SOLAR SYSTEM

"Whence sprang this world, and whether framed
By hand divine or no."

Man, with all of his limitations, has throughout long ages been asking whence came the earth, his home, and the sun and stars in the canopy of the heavens above. It is, however, only within the past few centuries that this inquiry has been pursued along scientific lines, and the problem for more than a century has occupied the central place in astronomical thought. Nevertheless the solution is not yet finally at hand, and in the following pages different hypotheses will be presented. The one accepted in this text-book as the most reasonable is that of Chamberlin and Moulton, which postulates the evolution of the solar system out of the sun itself through the accident of close approach to another star early in their respective careers.

There is no study more awe-inspiring than astronomy. It takes us beyond the earth, moon, and sun to the bright stars, and beyond the stars to the countless spiral universes. The measurable distances between the stars are so vast as to be beyond all actual understanding, and beyond them space is thought to continue without limit. "There are, perhaps, a million other universes, as large as our own and each with a billion suns, within the ken of our great telescopes" (Curtis). Space without limit, through which are moving countless systems of orbs in wondrous array: such is the majesty of the greater universe. And everywhere throughout this universe there is law and therefore order. It is the vastness of astronomy that makes all the more unanswerable the question, What does it all mean? Thinking man has long been pondering over the stars, the infiniteness of space, the indestructibility of matter, and in his helplessness he has sought refuge in religion and in imagined supernatural powers that order the laws of nature. Who can deny, who can affirm?

The Nebulæ

When we look out into the nearer heavens we see the sun and some of its family of planets, composing the solar system. In the

space beyond occur the stars, and among and beyond them are found different kinds of nebulæ ("little clouds," so called because in the telescopes their matter looks like small clouds). The nebulæ, like the stars, are luminous masses, but are far less dense, and are strewn in space far less thickly than the stars. "Where stars are scarce, nebulæ abound, and where stars abound, nebulæ are scarce." Of the brighter nebulæ, two or three hundred have long been known to exist in and near the Milky Way, and about four hundred of all kinds are known in this region of the skies. These are the gaseous nebulæ. The great majority of nebulæ, however, known as the white, faint, or spiral nebulæ, are absent from this part of the heavens.

Green Nebulæ. — The gaseous nebulæ are condensing with extreme slowness into hotter masses and eventually into nebulous stars, but in some, no condensing centers are seen at all. The green nebulæ within the galaxy of stars are highly rarefied bodies of glowing gases, with surfaces enormously large in proportion to the heat content. Orion is one of these which may be seen with the unassisted eye. These green nebulæ are in the simplest, elemental condition of matter, consisting essentially of nebulium, and their material is in a state of change. As they appear to have no direct bearing on the evolution of a system like our solar system, however, they need not be further considered.

"It is quite possible, and even probable," says Campbell, "that gaseous masses have not in all cases passed directly to the stellar state. The materials in a gaseous nebula may be so highly attenuated, or be distributed so irregularly throughout a vast volume of space, that they will condense into solids, small meteoric particles, for example, before they combine to form stars. Such masses or clouds of non-shining or invisible matter are thought to exist in considerable profusion within the stellar system . . . That this material will eventually be drawn into the stars already existing in the neighborhood, or be condensed into new centers and form other stars, we can scarcely doubt."

Seemingly there should be no "black holes" or non-luminous spaces in the crowded portions of the stellar system. These holes in certain parts of the skies Campbell thinks are due to "invisible materials between us and the stars," in other words, the stars are here hidden by material that occults the light they are sending toward us. Newcomb and Kelvin have said that there is much more invisible matter in the stellar system than there is in the visible stars.

Spiral or White Nebulæ. — We have seen that the green nebulæ are associated with our system of stars, the galaxy, and that to this starry system belongs our sun with its family of planets and moons. But beyond the galaxy there are countless other nebulæ, the white ones, having a spiral-like structure. These spiral nebulæ we must consider in more detail, since they figure in certain theories of earth origin to be described in later pages.

It is now known that the great majority of the nebulæ are of this spiral type. Perhaps a million spiral nebulæ are within reach of the lenses of the large reflector telescopes. The cause of their white light is as yet unknown, though the suggestion has been made that it is the combined light of millions of suns (see Fig., below).

The dominant form of the white nebulæ is, as has been said, the spiral. The largest is the great nebula of Andromeda, hundreds of thousands of times greater in diameter than the distance from the earth to the sun, yet visible to the unassisted eye only on the clearest of nights, due to its extreme tenuity and tremendous re-

Fig. 27. — A brilliant spiral nebula in Canes Venatici. Photograph by Ritchey, Yerkes Observatory; two-foot reflector, six-hour exposure.

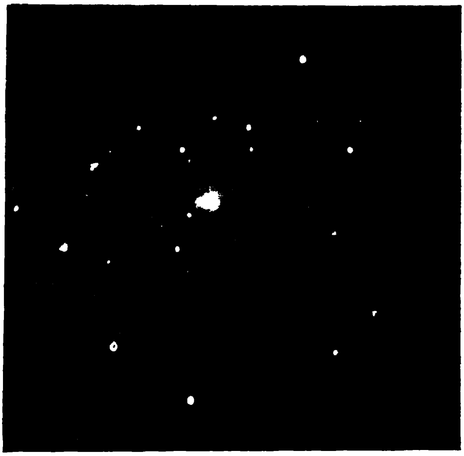

Fig. 28. — A typical spiral nebula in Pisces. Photograph by Lick Observatory.

moteness. Seen from the side, the spiral nebulæ are thin and disc-shaped; their matter is also irregular in distribution within the discs. Their most significant feature is the presence of two dominant arms that arise from diametrically opposite sides of the nucleus, and curve concentrically away. There are often more than two arms in the outer part, and there is much irregularly dispersed matter. The spiral arrangement is evidence that they are in rapid rotation.

Campbell asks, "Are the spiral nebulae in or attached to our system, or are they outside of our system, at tremendous distances from us? . . . The old hypothesis [of Herschel and Kant] that the unresolved nebulæ are other great universes of stars very far distant from our own universe of stars is receiving favorable consideration." Certain of the spiral nebulae "contain enough material to make . . . possibly millions of stars comparable in mass with our own

sun." Furthermore, their motions of approach and recession are very great, roughly from about twenty to thirty times faster than the motions of the average of stars in our stellar system. Campbell therefore favors the hypothesis that the spiral nebulæ are enormously distant bodies, independent stellar systems in different degrees of development, and independent of our stellar system. Humboldt long ago called them "island universes."

Evolution of the Stars

What a wondrous sight are the skies on a clear dark night, especially in the rarefied air of a mountain top or in the dry climate of the desert! We see distinctly hundreds of quivering stars, large and small, variable in color, all set in the deep black of boundless space. The Milky Way on the outer bounds of the galaxy extends across the whole sky like an irregular filmy cloud of silvery white, and it, too, consists of innumerable stars. The largest of all the apparent stars are of course best seen in the early evening and morning — the Evening and Morning stars, as we call them, though they are not stars but planets of our solar system shining by reflected light derived from the sun.

All of the true stars are self-luminous bodies and most of them exceed the dimensions of the sun by as much as forty times, while Betelgeuze is about 250 times the diameter of the sun (865,000 miles). The sun is the nearest star, and yet it is on the average some 93,000,000 miles away. The nearest fixed star, on the other hand, is more than 200,000 times farther away than the sun; nevertheless most people can see at any given locality at least 250 stars, and good eyes can make out about 800. The bright star Arcturus, emitting light very much like the sun, is calculated to be 50,000 times larger in volume than the sun, and 200 light-years from it. Light travels at the rate of 186,000 miles per second, and a light-year is equal to 63,000 times the distance between earth and sun. Stated in another way, a light-year has six million million miles.

The stars are all in motion, moving on the average about 16 miles per second. About 20 per cent appear to be motionless, but the rest are moving in two opposite directions, as if two swarms of bees were all intermixed and yet one of them passing through the other at apparently right angles.

Dark Stars. — There are also scattered throughout the heavens many "dark stars" that have run their course of evolution and are now externally cold and non-luminous. Their approximate number no one knows, but they probably outnumber the shining stars. Nor have we any knowledge of planets and satellites other than those

of our solar system, and it may be that some of these dark stars become comets of the sun's family.

Shape and Size of the Stellar System. — Astronomers tell us that the stellar system or galaxy (= aggregate of stars under one gravitative control) has roughly the shape of a very flat pocket watch. Its dimensions are enormous, and the astronomers of the Mount Wilson Observatory in southern California place the greater diameter at about two million light-years. Looking toward the equator of the stellar system or the Milky Way, we are looking through the greatest depth of stars, while the far lesser depth is in the axial or polar regions of the galaxy.

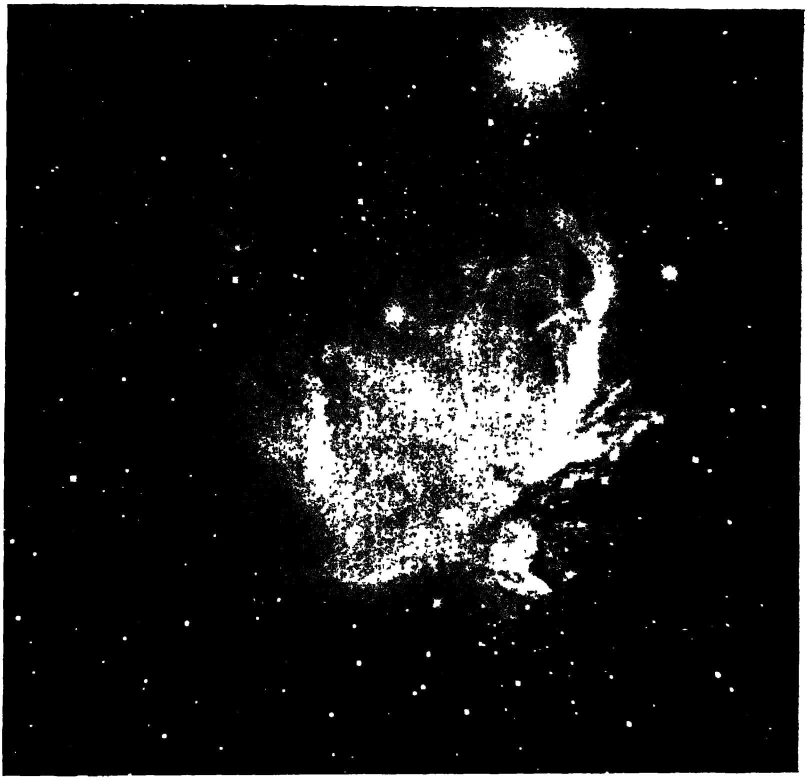

Fig. 29. — The great nebula in Orion, with irregular star condensing centers. Photograph by Ritchey, Yerkes Observatory; two-foot reflector, one-hour exposure.

Origin of Stars. — Stars develop out of nebulous matter, the green nebulæ in a gaseous state, and further evolution takes place through condensation and the loss of heat by radiation, resulting in smaller, more complex, and hotter stars.

The great nebula in Orion (Fig., p. 111) is held to be in the first period in the history of a star, for here the gas of nebulium is exceedingly tenuous and the stars condensing in it seem to indicate that the entire cloudlike nebulous mass is also in slow internal motion.

Giant Stars. — Astronomers have now ascertained the evolution of the stars far better than ever before, and they have been grouped into an ascending evolutionary series of heating giant stars, and a descending cooling series of dwarf stars. In other words, the giant stars are in the earlier stages of stellar evolution, are enormously larger than our sun, have a much lower temperature, and their gases are as diffuse as those in an electric vacuum tube. Jeans says that the volumes of the giant stars compared with those of the dwarf stars are of the ratio of about one million to one.

Betelgeuze, the red star in the constellation Orion, is one of the greatest of the known giant stars, with a diameter of about 215,000,000 miles (Hale). In volume it exceeds the sun at least a million times, although its mass is probably not more than ten times as great. The density of its gas can hardly exceed one-thousandth of our atmosphere. Three quarters of the naked-eye stars are in this stage, according to Hale, and Antares and Aldebaran are other examples. Slowly, with time, the giant stars contract through constant loss of heat by radiation, and yet their temperature rises, and as a result their color changes from red to bluish white. This process of shrinkage and rise of temperature goes on so long as the stars remain in the state of a perfect gas. The pinnacle of the ascending or heating evolution is reached in the intensely hot bluish-white stars of the helium class. The density of these stars is perhaps one tenth that of the sun, and the latter has a density of 1.4 greater than that of water.

Then follow the cooling stages, the descending part of the evolutionary cycle, for as soon as contraction has increased the density of the gas beyond a certain point, the temperature begins to fall. The bluish white light of the star becomes yellowish, and stellar evolution is now in the dwarfing part of the cycle. Our sun is a good representative of this stage. The density increases, surpassing that of water as in the case of the sun, and will go far beyond in later evolution. In the course of millions of years a reddish hue again appears, finally turning to deep red. The densest of known stars is the "New Variable," in position a little south of the Big Dipper. It is as solid as the surface rocks of the earth, with a specific gravity between 3.1 and 4.8. Curiously, it shines brightly, being of the eleventh magnitude. Accordingly we see that there are youthful giant red stars in which the gases are not much condensed, and dwarf red stars that are far advanced in their condensation. The latter are the oldest stars and are near extinction as light-givers. As the dwarf stars cool, the falling temperature permits the elements to unite into compounds of ever greater complexity. Finally, all light emission ceases and the star passes into its ultimate state, having a cold, dark exterior but with a more or less hot interior.

Helium Stars. — Through the study of the light (spectra) of stars it has been learned that the gaseous nebulæ of the Orion type

develop into stars that reveal dominantly helium. These are the bluish-white stars, the final stage in the ascending series of heating giant stars. The helium stars have the lowest known stellar velocities and the velocities of stars increase from the helium stars through the hydrogen and solar stars to the red stars. The helium stars are young, their motions are slow, and they have not wandered far from the place of their birth in the Milky Way. The more mature dwarf stars have wandered far from the place of their origin.

Hydrogen or Sirian Stars. — Next in order of evolution in the dwarfing series appear to be stars like Sirius, in which the spectrum is marked by conspicuous hydrogen lines, associated with inconspicuous ones of iron, sodium, magnesium, etc. They do not have

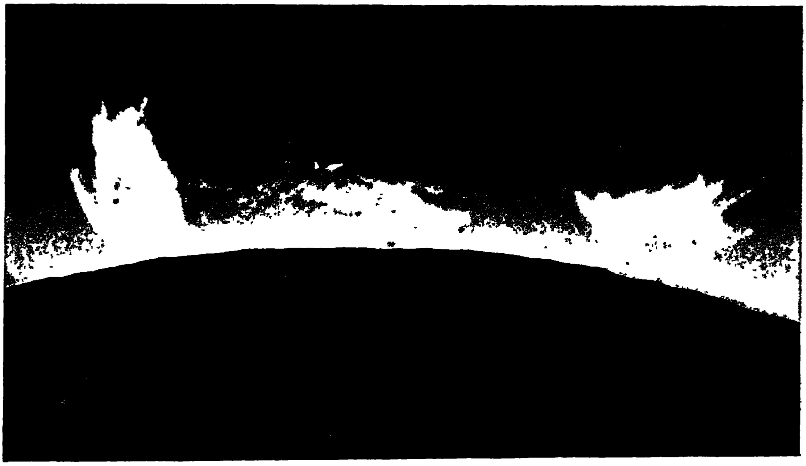

Fig. 30. — Solar prominences during the total eclipse of May 28, 1900. Photograph by Barnard and Ritchey, Yerkes Observatory.

dense absorbing atmospheres, and due to this fact and to their extremely high temperature, they are revealed to us also as the white or bluish white stars. These stars, though relatively condensed, are nevertheless much less dense than the sun.

Solar or Metallic Stars. — Further condensation produces more and more of a thick absorbing atmosphere, and the consequent filtering of the stars' light causes them to take on a yellowish or reddish tinge. Solar or yellowish stars are thought to have attained stellar maturity — are middle-aged stars — and like the sun have thick absorbing atmospheres; their interiors, however, are still gaseous, though under strong compression. The sun's temperature is of the order of 6000° absolute Centigrade, or nearly twice the

temperature of the arc light (see Fig., p. 113). The sun, like many other stars, is of the metallic type, somewhat hotter than the reddish yellow or Arcturian type, and the spectroscope reveals in it the presence of vapors of iron, sodium, magnesium, calcium, hydrogen, and many other elements known on the earth, but in general no compounds of elements occur (Abbot).

Hale describes the appearance of the sun at times of total eclipse as follows: Red flames of hydrogen, sometimes reaching heights of five hundred thousand miles, may be seen rising from a continuous sea of flame, which completely encircles the sun (see Fig., p. 113). These are the prominences, and the continuous mass of flame from which they rise is the chromosphere. Extending far beyond these flames into space, sometimes to a distance of millions of miles, is the corona, which shines with a silvery luster somewhat inferior in brightness to that of the full moon.

Carbon or Antarian Stars. — The stars in their continued evolution beyond the solar stage eventually fade further and further toward invisibility. From the yellowish stars we pass to those of an orange or red color, the spectra of which reveal marked carbon lines. The latter is the last period of stellar visibility.

Dark Stars. — Finally the evolution continues into the dark or invisible stars, of which many are known to exist by the gravitative disturbance which they exert upon the neighboring stars. The last stage will be the formation of a hard outer shell, but no life will be evolved because there will be no light to supply the necessary environment for organisms. The original motion, however, will continue, and therein lies the possibility of a future cataclysmic approach to some other star.

Rapidity of Stellar Evolution. — "Speaking somewhat loosely, I think we may say that the processes of evolution from an extended nebula to a condensed nebula and from the latter to a spherical star, are comparatively rapid, perhaps normally confined to a few tens of millions of years; but that the further we proceed in the development process, from the blue star to the yellow, and possibly but not certainly on to the red star, the slower is the progress made."

"There are reasons for suspecting that the processes of evolution in our sun, and in other stars as well, may be enormously prolonged through the influence of energy within the atoms or molecules of matter composing them. The subatomic forces residing in the radioactive elements represent the most condensed form of energy of which we have any conception. It is believed that the subatomic energy in a mass of radium is at least a million-fold greater than the energy represented in the combustion or other chemical transformation of any ordinary substance having the same mass. These radioactive forces are released with extreme slowness, in the form of heat or the equivalent; and if these substances exist moderately in the sun and stars, as they do in the earth, they may well be important factors in prolonging the lives of these bodies." (Campbell.)

New Stars. — As we have seen, there must be in the galactic universe countless numbers of dead stars, any one of which may at some future time, through the accident of close approach to another star, be set ablaze for a time. The novæ or new stars may be due to such stellar catastrophes.

In the early stage of galactic evolution, close approach, Jeans says, must have happened often, since the stars were then much more closely spaced than they are now, their relative velocities probably much smaller, and their densities very low.

The new stars are superb stellar catastrophes suddenly flashing out in the sky, and nearly always in the Milky Way, where previously no star was known to exist. Their known number is not large. They usually rise to maximum brilliancy in a few days, and some have increased in brightness ten thousandfold in two or three days. They become invisible in a few weeks or months.

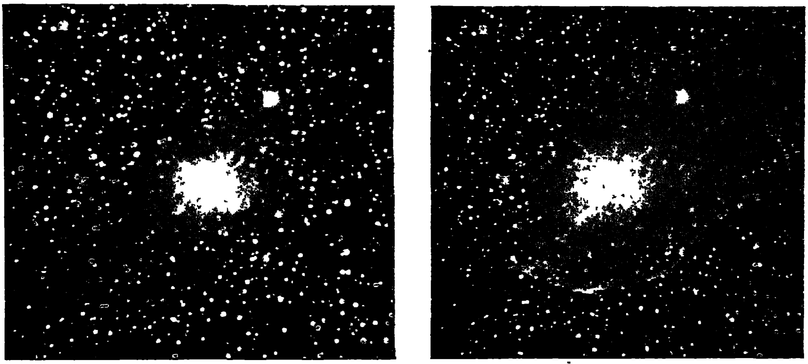

Fig. 31. — The new star in Perseus in 1901, showing expansion of nebulosity from September 20 to November 13. Photograph by Ritchey, Yerkes Observatory.

"A nova," Campbell says, "is seemingly best explained on the theory that a dark or relatively dark star, traveling rapidly through space, has encountered resistance, such as a great nebula or cloud of particles would afford. While passing through the cloud the forward face of the star is bombarded at high velocities by the resisting materials. The surface strata become heated, the luminosity of the star increases rapidly." Reynolds (1923) holds that novæ pass into planetary nebulæ.

Meteorites and Comets

We must here digress a little to study the meteoritea, since "they fairly represent the nature of any kind of scattered interplanetary matter of the solid type that might once have been available for the formation of small planets and satellites," as postulated in the Chamberlin theory of earth origin, soon to be described.

On almost any dark night may be seen brilliant white or green

streaks of light shooting with high velocity and in divers directions through the skies. These fiery lines, popularly called "shooting stars," and "falling stones," are caused by bodies of solid matter, those reaching the earth varying in size from 5 grams to at least 37.5 tons (Figs., pp. 116, 117). Although but few are seen by the eye, it is estimated that 20,000,000 strike the earth or its atmosphere each day, and yet only about 815 (260 American) falls are known to geologists. It is thought that about 100,000 tons of meteoritic dust are added annually to the earth. The meteorites are "unquestionable fragments" of other worlds moving swiftly through our atmosphere. The initial velocity of impact is so high, up to 45 miles per second, that the meteors are heated to the point of dissipation as a luminous gas by the friction generated in passing

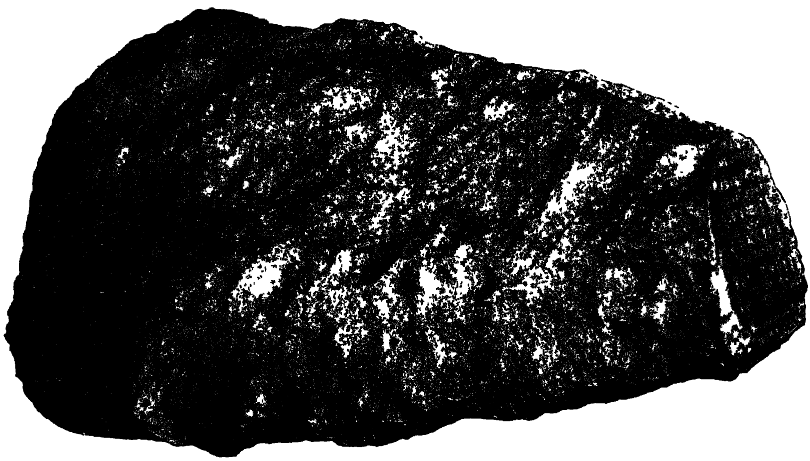

Fig. 32. — The Gibbs nickel-iron meteorite found in Texas. Weight 1635 pounds. At Yale University (Peabody Museum).

through the terrestrial atmosphere. Thus they become visible only at the moment of their dissolution, and this is dependent upon the accident of collision with the earth.

Meteorites appear to be disintegrated comets, attracted to the sun and earth from the outer confines of solar space. They bring to us samples of their bodily constitution and the proof that they are closely related in their chemical elements to our own sun and earth, though differing in the proportional amounts and sometimes radically in their combinations. More than forty elements are known in meteorites, the most abundant being aluminium, calcium, carbon (as graphite and diamonds), iron, magnesium, nickel, oxygen, phosphorus, silicon, and sulphur.

There is a considerable variety of meteorites and these are grouped by Merrill as follows: (1) stony meteorites (basaltic and chondritic) or *aërolites*, consisting essentially of silicate minerals with minor amounts of the metallic alloys and sulphides (Fig., below); (2) stony-iron meteorites or *siderolites* of metal and silicate minerals; and (3) large iron meteorites or *siderites*, essentially of an alloy of nickel, iron, and cobalt, with iron phosphides and sulphides (Figs., pp. 116, 118). "It is evident that the meteorites were formed under conditions of a limited supply of oxygen and that they have since their formation been subjected to high temperatures and the reducing power of gases" (Merrill).

Chamberlin regards meteorites as "but an incidental result of stellar and planetary action. Their genesis is wholly a secondary matter, and furnished no ground for regarding meteorites as the parent material of great nebulæ or of stellar systems. . . . This scattered matter is presumed to be picked up bit by bit by all the larger bodies, as is being done daily by the earth."

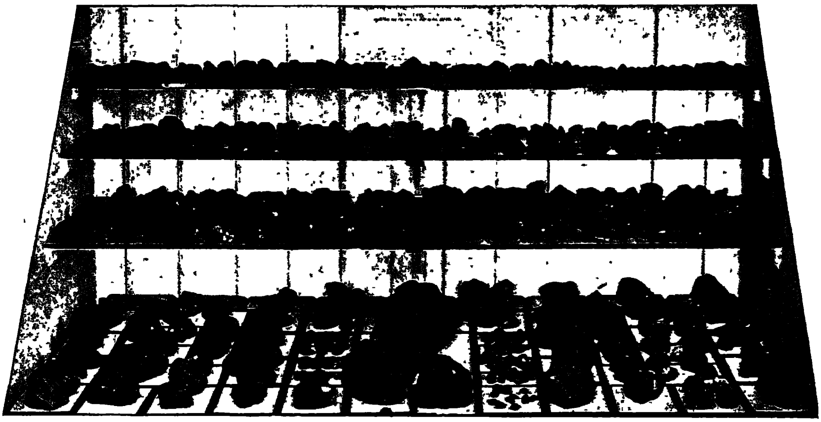

Fig. 33. — A stony meteorite that fell at 5 P.M. on May 26, 1890, in Winnebago County, Iowa. In exploding it broke into several thousand fragments, more than eight hundred of which are here shown. The largest piece weighed 80 pounds. At Yale University (Peabody Museum).

Comets and their Relation to Meteors. — Comets, compared to the earth or moon, are decidedly smaller bodies, and they are now members of the constellation of the sun. Originally they were dark interstellar bodies deflected from their paths by the mass attraction of the solar system. They spend most of their time in the outermost parts of the solar system and swing around the sun usually from west to east. Most of them are seen but once, but at least sixty are periodic, and revolve in short ellipses about the sun. Comets develop tails on approaching the sun, consisting of gases and the finest of dust that is blown away into space by the light pressure and is then seen by reflected light from the sun.

The heads of the periodic comets are more diffuse in appearance than the others and it is believed that they consist principally of discrete small bodies held together by their own slight gravitation. With each return to the sun, the parts are more and more scattered and eventually the comet becomes invisible but appears to retain its cometary orbit as a swarm of meteors. Five such swarms are known: those of April and August, the Perseids; those of November, the Leonids; and Biela's comet. "Clearly," says Campbell, "the cometary materials had been gradually scattered by the disintegrating effect of the sun's attraction, and the separate particles were compelled to move in orbits differing slightly from each other, and from the recognized orbits of the comets."

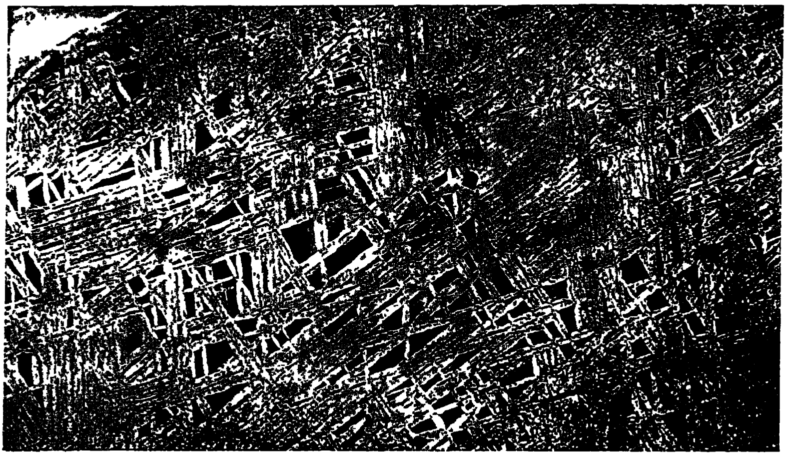

Fig. 34. — Section of the Grand Rapids, Michigan, meteorite, showing the coarse crystallization of the nickel-iron (Widmanstätten figures). Natural size. At Yale University (Peabody Museum).

Theories of Solar Origin

Geologists and astronomers are now more and more giving up Laplace's theory of the origin of the earth out of the sun, and accepting more or less of the Chamberlin-Moulton hypothesis. The latter explanation will, however, be better understood if we give the history of the rising Laplacian theory.

Nebular Hypothesis of Kant. — Astronomy and physics received a great impetus from Newton's principle of universal gravitation, given to the world in 1687, a principle that led to a sound conception of the evolution of the solar system. This Newtonian principle was the basis of Immanuel Kant's nebular hypothesis,

which that professor of mathematics and physical geography at Königsberg presented in 1755.

Kant, according to Iddings, conceived that the universe might have been developed out of chaos and that space was filled with fundamental material highly varied as to mass, density, and power of attracting other particles. He argued that since the planets and their satellites moved in strict conformity with one another and in definite relation to a central sun, with vacant spaces between

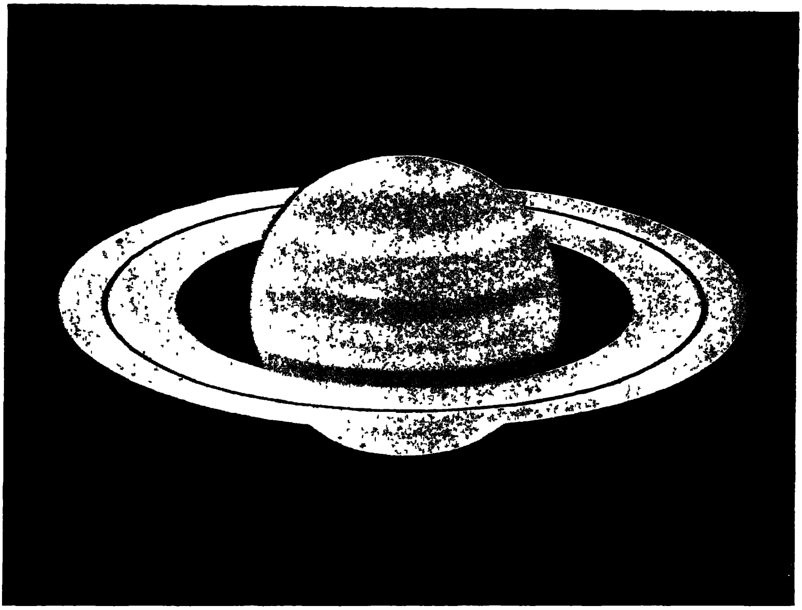

Fig. 35. — Saturn as seen with the 36-inch refractor. Drawing by J. E. Keeler, Lick Observatory. The outer ring has a diameter of 172,610 miles, a width in its plane of about 11,000 miles, and a thickness estimated at 50 miles. The space inside the outer ring is 2200 miles, and the second ring is about 18,000 miles wide. The dark or crape ring is about 11,000 miles wide, with its inner edge less than 6000 miles from the surface of the planet. The equatorial diameter of the planet is 76,470 miles. (Moulton.)

them, there must have been a diffusion of their substance through space, and a subsequent segregation into planetary masses.

The attraction of the particles for one another would occasion motion in all directions throughout the swarm. The denser would in time become nuclei of condensation. Finally there would thus result zones or rings of discrete particles segregating into condensing nuclei, which upon further condensation become planets and satellites, the preponderating central nucleus becoming the highly heated sun.

"Kant's hypothesis," Campbell says, "had the great defect of trying to prove too much. It started from matter *at rest,* and came to grief in trying to give a motion of rotation to the entire mass through the operation of internal forces alone — an impossibility. Kant's idea of nuclei or centers of gravitational attraction, scattered here and there throughout the chaotic mass, which grew into the planets and their satellites, is very valuable."

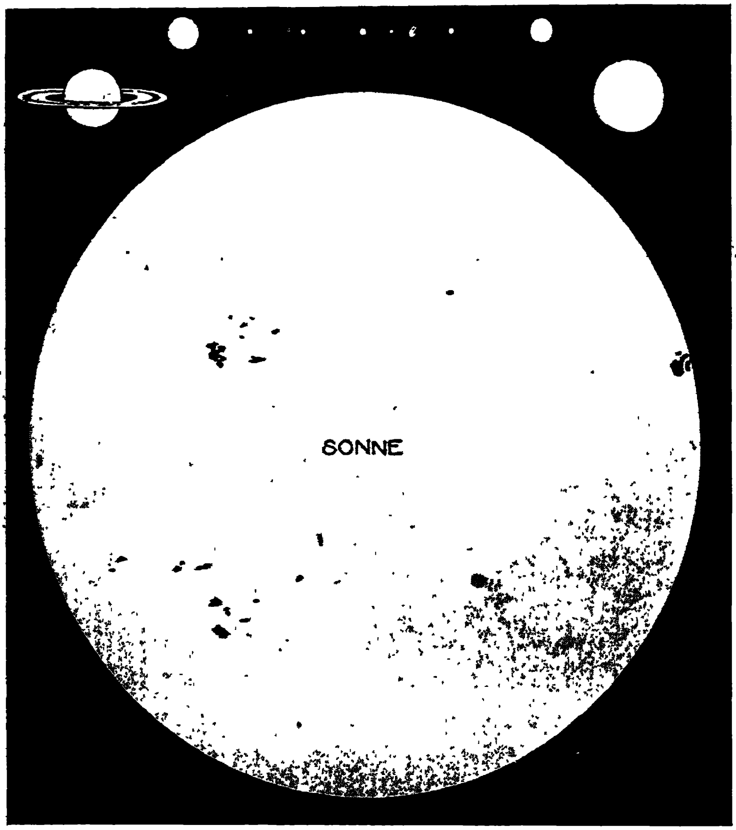

Fig. 36. — The sun (with sun-spots) and eight planets in true size relations. Above, from left to right, are Saturn (with 3 rings and 9 satellites), Neptune (1 satellite), Mercury, Mars (2 satellites), Earth and Moon, Venus, Uranus (4 satellites), and Jupiter (9 satellites). From Kayser's *Abriss der Allgemeinen und Stratigraphischen Geologie,* 1922.

Nebular or Hot-earth Theory of Laplace. — The celebrated theory of the French astronomer Laplace explaining the origin of the solar system dominated the world's thought from the date of its publication in 1796 and its further modification in 1824. Laplace thought that our ancestral sun, long before it gave birth to its family of eight planets (four outer large ones and four inner

small ones), their twenty-six satellites, and the ring of more than nine hundred very small planetoids, was originally in a state of luminous vapor. It extended even beyond the orbit of the outermost planet Neptune. In other words, the vaporous sun then had a diameter of not less than 5,600,000,000 miles, and its gas must have been unbelievably thin, several hundred million times less dense than the air we breathe.

Laplace pictured our ancestral sun as a rotating nebula of gas that was slowly contracting through loss of heat by radiation, and leaving behind nine rings of gas liberated from the equatorial region of its mass, each one of which condensed either into a planet or a ring of planetoids. Important as was this birth of the planets, their total mass is not more than one half of one per cent that of the sun. However, according to Campbell, successive abandonment of nine gaseous rings of matter, each ring rotating as if it were a solid structure, is unthinkable.

Laplace also held that the gaseous planets similarly left behind one or more equatorial rings that have since condensed into moons. In the case of Saturn (see Fig., p. 119), some of the rings remained as such, but it is now known that these are not gaseous but composed of fragmented solid material. However, as all the satellites should revolve in the same direction as their planet parents, i.e., from west to east, clockwise, it is fatal to Laplace's theory that eight of them do not follow this rule; these are the four moons of Uranus, the one of Neptune, the ninth or outermost moon of Saturn, and the eighth and ninth moons of Jupiter.

Objections to this theory were brought forward at various times during the nineteenth century, and some of them have already been mentioned. Others are: (1) No nebulæ closely resembling the supposed annulated one that gave rise to the solar system have yet been discovered. (2) The very extended solar mass in rotation would violate fatally the law of constancy of moment of momentum (the technical term for energy of the rotating body). (3) The Laplacian solar system should be regular in all of its parts, but the solar system as it exists is a " combination of regularities and many surprising irregularities " (Campbell). (4) Even if the rings had formed, Moulton has shown that it would have been impossible for this nebular material to draw together into a planet.

Jeans's Theory of the Evolution of the Galaxy and Solar System.—According to Jeans, in the beginning all the stars within our galactic universe formed a single mass of excessively tenuous gas in slow rotation. This mass contracted owing to loss of energy by radiation,

and so increased its angular velocity until it assumed a lenticular shape. After this, further contraction was a sheer mathematical impossibility and the system had to expand. The mechanism of expansion was provided by matter being thrown off from the sharp edge of the lenticular figure; the lenticular center now formed the nucleus of a spiral nebula of the normal type, and the thrown-off matter formed the arms. (See Fig., p. 109.) The long filaments of matter which constituted the arms, being gravitationally unstable, first formed into chains of condensations about nuclei, and ultimately formed detached masses of gas. With continued shrinkage the temperature of these masses increased until they attained incandescence and shone as luminous stars. The majority of the stars broke away from their neighbors and so formed our present galactic universe, in which the flattened shape of the original nebula may still be traced in the concentration about the galactic plane, while the original motion along the nebular arms still persists in the form of "star-streaming."

The solar system of the galactic universe has, however, not been formed as the result of a rotational break-up, as have our galaxy and the spiral nebulæ, but developed out of tidal disruption caused by the close approach of another star to the sun.

At intervals it must have happened that two stars passed relatively near to one another in their motion through the universe. We conjecture that our sun experienced an encounter of this kind, a larger star, one above the average, passing within a distance of about the sun's diameter from its surface. The effect of this would be the ejection of a stream of gas from the sun toward the passing star. At this epoch the sun is supposed to have been dark and cold, its density being so low that its radius was perhaps comparable with the present radius of Neptune's orbit. The ejected stream of matter condensed into detached nuclei which would ultimately form planets. The more liquid planets at the end of the chain would be those of smallest mass; the gaseous center of the ejected chain of matter would form the larger planets Jupiter and Saturn.

Planetesimal or Cold-earth Theory of Chamberlin and Moulton. — These authors postulate that the materials now composing the sun, planets, and satellites must have had a "biparental origin." Due to a close approach, "a nebula was evoked *from* the sun to form its attendants." In other words, the secondary solar nebula "was little more than a streaming knotty pair of arms of nebulous matter shot from the sun and curved into spiral appendages about it by the joint pull of itself and a passing star."

"Chamberlin and Moulton's hypothesis has the advantage of a parent mass in rotation, practically in a common plane, and with the materials distributed at distances from the nucleus as nearly in harmony with the known distribution of matter in the solar system as we care to have them. . . . In effect it retains all the advantageous qualities of Kant's proposals. It seems to have the flexibility required in meeting the irregularities that we see in our system" (Campbell).

The knots of the solar nebula play a leading part in the interpretation of the immediate genesis about them of the planets, planetoids, and satellites, since they served as collecting centers for the dispersed dust-like material, the *planetesimals*, the minute particles of the secondary solar nebula.

The student must be careful not to confound the solar nebula, which was spiral in form, with the vast spiral nebulæ, the "island universes," since the latter condense into galaxies, while the solar nebula gave rise only to the constellation of the sun.

Fig. 37. — Thomas Chrowder Chamberlin (1843–). Propounder of the planetesimal theory of earth origin.

According to the planetesimal hypothesis, there were six stages in the growing earth before geologic time began. These may be described briefly as follows:

(1) *Nuclear Stage.* — The earth started in a nebular knot, the diameter of which may have been between 2000 and 3000 miles. At first the discrete matter was held together by mutual gravity, and later the whole passed gradually into a solid mass.

(2) *Initial Volcanic Stage.* — Before the nucleus grew to any large part of the earth's present mass, the self-compression which arose from its own gravity, when at a diameter of less than 3000 miles, is thought to have produced sufficient central heat to have reached the melting points of the common kinds of rock under low pressures. Accordingly there soon appeared volcanic activity at the surface of the growing earth. The internal heat may in part have been produced by the infall of planetesimals, and an unknown amount was probably inherited from the nebular

knot that constituted the original earth-nucleus. The chief source of internal heat is, however, assigned to the progressive interior condensation of the growing body as planetesimals were added to its surface. Another source of heat lay in the atomic and molecular rearrangement of the growing nucleus.

(3) *Initial Atmospheric Stage.* — In the nuclear stage the earth was too small to hold to its surface the gases of an atmosphere, but when it had a mass at least one tenth of its present one, it probably held a limited atmosphere as does Mars. As it grew larger, it began to attract atmospheric molecules and developed the power of holding an atmosphere. The diameter of the earth may then have been about 4200 miles, and with the origin of volcanic action, more gases were added to the atmosphere.

(4) *Initial Hydrospheric Stage.* — When the earth had attained sufficient size, water vapor was held in the atmosphere, and when, at length, the point of saturation was reached, it took the liquid form and initiated the hydrosphere. When the water accumulated upon this surface, it did so in innumerable small depressions or lakes. These bodies of water initiated the oceanic basins. Therefore the differentiation of the heavier oceanic regions from the lighter continental protuberances began almost as soon as the hydrosphere started to gather, or when the earth had attained the size of Mars.

(5) *Initial Life Stage.* — Suitable conditions for life did not exist until after some notable development of the atmosphere and the hydrosphere, but it is possible that certain forms of life originated long before the earth was full-grown.

(6) *Last Stage of Planetesimal Accretion.* — During all the previous stages the earth was slowly growing larger, and according to Chamberlin, it grew very, very slowly. Finally, the time came when practically all of the planetesimals of the original nebula under the influence of the attraction of the earth and the moon had been gathered. The earth probably then had a considerably greater equatorial diameter than now. This stage ended Cosmic time in the history of the earth.

(7) *Gradational Stage.* — After the growth of the earth had ceased, the surface was no longer subject to continual burial, but was exposed ever afterward to the action of air and water, and heat and cold, wearing away the high places to fill the lower ones. The seventh stage, therefore, embraces all geologic time, and its dominant process was gradational.

If the earth was built of meteorites like those seen to fall on the earth, which have a mean specific gravity of 3.69, and if the meteorites were as small as dust,

rigid, and elastic, then the earth at the close of its growing period must have had a radius of 4530 miles, with the present specific gravity of 5.53. This is 570 miles greater than the present radius (3959 miles). Originally porosity was far greater because of the granular nature of the planetesimals. Accordingly the earth has shrunk about 570 miles since the beginning of its growth (Chamberlin).

Planetoidal or Hot-earth Theory of Barrell. — We have seen that according to Chamberlin the planetesimals were in the main of dust size, and that it took an immensely long time for the earth and moon to gather them. Barrell (1918), on the other hand, viewing the probable size of the planetesimals as equivalent to that of the planetoids, inclined to the idea of *rapid* infall of material upon the earth nucleus. Accordingly, but little time was consumed during the growth stages of the earth, and the infall of masses mainly large and up to hundreds of miles in diameter led to the formation of a hot earth.

According to Barrell, from one fourth to one half of the whole material shot out of the sun was in the knots, the remainder in planetoids and planetesimals. Four small knots represented the beginnings of the four small inner planets. Beyond them was the zone of the planetoids, and as here there was no dominating nucleus, they have therefore remained to this day largely in the planetoidal state. Outside of the latter were the four greater nuclei, the beginnings of the four major planets. These nuclei and planetoids gathered the planetesimals within the spheres of their attracting powers.

Chamberlin conceives the earth to have been built up as a solid body, not to have been fluid or viscous at any time later than the early nuclear stage. Such liquid rock as was generated by compression or radioactivity during earth-growth is regarded as having been kneaded and squeezed to the surface, where it solidified approximately as fast as it was formed.

On the other hand, Barrell holds that the chemical character of the igneous rocks, the limited depth of density variations in the crust, the limited amount of the salt in the sea, the rotation periods of the moon and planets all point to a molten condition of the earth at the completion of its growth. If the earth began to have an ocean when about one half of its present diameter and one eighth of its present volume, then the oceans should be far more salty than they are, because seven eighths of their accreted materials underwent weathering and should have yielded their salts to the oceans.

The argument for an eventual molten earth, Barrell deduces as follows: The belt of asteroids, better called planetoids, appears

to have remained more nearly in its original state than have other parts of the solar system. The diameters of the known asteroids range from a maximum of 485 miles in increasing numbers down to 15 or 20 miles, the limit of telescopic visibility, and countless others must be so small that they will remain unseen. All the asteroid masses together, according to recent calculations, are equivalent to less than one-hundredth of the mass of the earth. Therefore the invisible parts of this ring of asteroids are not in dust-like or molecular form, but are in fragments of appreciable size, ranging up to some miles in diameter. Furthermore, these masses, owing to their small diameters and hence weak gravitative force, would possess almost no power to grow by accretion. They must retain almost the original stage of the nebula, or better, the meteoritic swarm. Their evidence therefore favors the view that the scattered matter which was added to the nucleus to form the earth was largely of such size that the individual planetoids would have penetrated beneath the surface of the liquid or solid earth. The energy of impact of the larger masses would result in local liquefaction. If in addition the infall of the planetoids was sufficiently rapid to bury the heat of previous infalls before it could be dissipated by conduction to the surface, a general heating and liquefaction of the earth would tend to take place, both from the increased compression of the deeper nucleus and the effects of impact at higher levels.

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CHAPTER IX

THE EARTH BEFORE GEOLOGIC TIME

In the previous chapter was described the evolution of the stars that leads on to the origin of the solar system and the earth. As we have seen, most hypotheses derive the sun and planets from an antecedent solar nebula, and other theories develop the earth out of a meteoritic swarm born of the sun. All agree, however, that the sun, like the stars, condensed out of nebulous matter. In regard to the origin of the earth, the theory that is most acceptable is the planetesimal hypothesis, which states that the sun while in its early gaseous condition approached another star and was partially disrupted through tidal action set up between the two bodies. Out of the ejected material, become cold, evolved the planets and their satellites. The early stages of the growing earth, as postulated by this theory, will now be set forth in more detail.

Fig. 38. — Joseph Barrell (1869–1919). An original thinker along many lines in Geology.

In the previous chapter we saw that the planetesimal hypothesis of Chamberlin and Moulton postulates the growth of the earth and moon through the very slow accretion of cold planetesimals, in the main the size of dust, upon two original nuclei. Since, however, we shall follow here Barrell's conception of earth growth through planetoids that originally were clustered and averaged large in size, quickly accumulating about the nuclei and giving rise to a molten earth, it is now in order to develop this theory further. Nevertheless we must not forget Joly's conclusion that the original molten condition of the earth may have been due " to accumulated radio-

active condensation." Of course, it can not be known whether during earth growth the center, or material of the original knot, tended toward a liquid or a solid state. The outer part, however, with a thickness of perhaps the outer quarter of the radius, comprising about one half of the volume of the sphere, seems to have passed into a truly molten condition.

After a long time, the rapid generation of heat by impact of the planetoids lessened, and the fluid sphere, seething with slow convection currents, began to cool. The heavy basic crystals were the first to form, and because of their high specific gravity they sank downward in the convective movement. The remaining higher magma was more siliceous, of lighter gravity, and in crystallization gave to the crust a greater proportion of feldspar and quartz. *The original crust of the earth was in consequence a granite.*

Spheres of the Inner Earth. — The vast central mass of the earth, the *centrosphere* or barysphere, is some 6200 miles in diameter. It appears certain that pressure is the dominant factor within this earth nucleus. If the composition of the earth as a whole is similar to that of the meteorites, then the inference is that the material of the centrosphere is of metallic nickel-iron (NiFe, called nife by Suess). The blast furnace makes familiar the fact that slag is insoluble in iron and, being lighter, gathers in the upper part of the crucible, like cream upon milk; and slag is similar in composition to basaltic igneous rocks. The density of the deep interior suggests that it is layered like the material in the crucible of the blast furnace, and that the silicate rocks form an envelope some hundreds of miles thick, grading down into a great metallic core.

The silicate envelope, something like 900 miles thick radially, ultimately differentiated further, resulting in a rise of the more siliceous and lighter fraction into an outer layer, the very strong *lithosphere* or rock sphere (SiAl or silica and alumina, called sial by Suess, sal by others), perhaps 50 to 75 miles in thickness. This in turn crystallized into a primordial universal granitic crust, above a thicker basaltic shell below (SiMa, written sima by Suess). (For other details, see Pt. I, pages 263–264.)

Between the lithosphere and the centrosphere lies a hot, basic (mainly of basalts and gabbros), rigid, yet weak shell which Barrell has called the *asthenosphere*, meaning the sphere of weakness. It is marked by a capacity to yield readily to long-enduring strains of limited magnitude, — a zone of earth weakness composed of yielding matter.

The earth as a whole is very rigid, as dense and rigid as is armor steel, or glass.

"The lithosphere was once thought to be the restricted province of geologists, but they now lay claim to the entire earth, from the center of the centrosphere to the limits of the atmosphere, and they threaten to invade the region of the astronomers on their way towards the outlying domain of cosmogony. Geology illustrates better than any other science, probably, the wide ramifications and the close interrelations of physical phenomena. There is scarcely a process, a product or a principle in the whole range of physical science, from physics and chemistry up to astronomy and astrophysics, which is not fully illustrated in its uniqueness or in its diversity by actual operations still in progress on the earth, or by actual records preserved in her crust. The earth is thus at once the grandest of laboratories and the grandest of museums available to man" (Woodward).

Azoic Era

The present diameter of the earth is 7918 miles, but at the close of the growing period or the beginning of the hypothetic Azoic era, it must have been 200 and possibly even 500 miles greater radially, for it is well known to geologists that throughout geologic time it has been losing volume due in part to the loss of heat into space, but probably in greater degree to internal molecular change. Even though the earth has thus been dissipating its inherited energy for at least many hundreds of millions of years, our mundane sphere is still far from having attained the internal stability that will, when achieved, probably result in a featureless earth with a universal ocean, and an atmosphere devoid of carbon dioxide, the basis of life. Then the earth will be in its old age.

Dana, following the Laplacian conception of a molten earth origin, called the first era in the earth's history the *Astral eon*, when the earth was thought to be in the condition of a star. This gaseous state evolved into a fluid earth surrounded by a heavy vaporous atmosphere.

The Astral eon was followed, according to Dana, by the *Azoic eon*, when the hot earth became encrusted, but was still lifeless. This eon he subdivided into an earlier *Lithic era*, when the earth had cooled enough to have a solid rocky crust, the original crust, composed wholly of crystalline rocks, dominantly granite; and a later *Oceanic era*, when the previous heavy atmosphere had condensed into a universal ocean.

Tidal action now set in, oceanic waves and currents and rivers commenced their work about the emerged and emerging lands, and sediments accumulated for the first time. The large excess of carbonic acid in the air and water became a source of rock destruc-

tion. Before the close of the era, there arose the formation of limestones and iron carbonates by chemical methods, removing carbonic acid from the air and so commencing its purification.

The Primordial Atmosphere. — Geology now holds that the atmosphere and hydrosphere are essentially of volcanic origin, being the accumulated exhalations of active volcanoes and thermal springs. The gases come from deep within the earth, from heated and altering molten magmas. They are conceived of as dissolved in highly compressed magmas, and when the pressure is relieved, the gases heat the magmas and finally escape into the atmosphere.

Granting the initial fluid state of the earth, Barrell goes on to say, there must have been a hot gaseous atmosphere consisting chiefly of water-vapor, and in lesser amount, carbon dioxide and carbon monoxide, chlorine and hydrochloric acid, with some nitrogen but no free oxygen.

The primitive atmosphere penetrated by solution deeply into the universal molten rock. This penetration of water-vapor made it possible for the fluid rock to remain fluid at 800° C., whereas without water, dry silicate magmas melt only between 1300° and 1500° C. As there would be but little dissociation of water into its component gases, therefore the primordial atmosphere would be one of water gas, with an abundance of carbon dioxide and carbon monoxide.

The sunlight of Azoic time finally illumined the earth and was reflected from the mantle of cloud. The planet shone brilliantly by this reflected light, similar to that which Jupiter and Saturn still possess. Above the zone of cloud the carbon dioxide and other gases, with very minor amounts of water-vapor, extended with diminishing density as an upper transparent envelope.

Henderson in his interesting book, *The Fitness of the Environment*, says that the nature of the chemical combinations into which the elements hydrogen and carbon at first enter is perhaps open to question. But as the temperature falls in the cooling of a sun or planet, the affinities of carbon and hydrogen for oxygen increase, so that carbonic acid and water must normally result. For oxygen is almost certainly present in the sun; it is found in meteorites, and the vast store of it in the earth's atmosphere and crust (roughly one half of their total mass) justifies the belief that it is everywhere one of the commonest of elements. Hence an atmosphere containing water and carbonic acid appears to be a normal envelope of a new crust upon a cooling body. Even were these substances not present at first in such an atmosphere, volcanoes must soon belch them forth in enormous quantities to relieve the pressure which inevitable chemical processes set up.

In the earth's atmosphere, carbonic acid has been very largely converted into oxygen and vegetable matter, which later have been turned into enormous quantities of coal. It is, in fact, possible, in accordance with the suggestion of

Koene, that all the oxygen of the atmosphere has been thus formed from carbon dioxide, and that therefore coal, peat, and other similar substances within the earth are chemically equivalent to the oxygen now free.

The most constant accessory constituent of air is carbon dioxide, which is of vital importance to life. In the present atmosphere there are about 3 volumes of this gas to 10,000 of air, and there is as much more in living things as there is in the atmosphere. On the other hand, there is in the oceans of to-day, according to F. W. Clarke, from eighteen to twenty-seven times more carbon dioxide than in the air (Johnston and Williamson say that at 15° C. there is about seventy times more), while the still vaster volumes locked up in the sedimentary rocks and in the fuels and carbonaceous deposits of the earth are computed to be 30,000 times greater than the volume in the present atmosphere. These facts are brought forward at this time to show that the constituents of the atmosphere have always varied because of the constant loss of carbon dioxide and oxygen to the sedimentary rocks, but that at the same time there has always been a resupply of carbon dioxide through the periodically active volcanoes and the mineral springs, and of oxygen through the life activities of plants.

Gathering of the Ocean Waters. — When the crust began to cool and changed from a fluid to hard rock, Barrell says crystallization went forward in various areas, convection was slowed, and finally the molten rock froze. Then rain, ever descending from the shield of perpetual cloud, but never heretofore attaining the lithosphere, at last began to splash on the hot surface of the earth. A steaming earth's surface was of short duration, perhaps only a few thousand years. Then the surface began to assemble an ocean of acid water, probably universal over the lithosphere. Carbon dioxide became the dominant gas in the rare atmosphere, and water-vapor was present in subordinate amounts. Solar heat began to play the principal part in warming the earth through the now thin and broken cloud canopy. For the first time sunlight attained the surface of the lithosphere.

Volcanic activity was still very great and great volumes of gases were liberated, adding juvenile materials to the old or vadose atmosphere and hydrosphere. Ever since, new quantities of juvenile water and carbon dioxide have been added to the surface of the earth by the volcanoes. At first, the volume of water added was great, but since early in the history of the earth it has lessened, we may say that the body of the earth has given forth its oceans. The greatest amount was added during the Azoic and Archeozoic eras, when from 50 to 75 per cent of the present volume is believed to have come into existence. The rest has been added during subsequent geologic time.

Origin of Continents and Oceanic Basins. — It is well known to geodesists and geologists that the continents are built of lighter

materials, essentially of granites, while the greater oceanic areas have heavier basaltic rocks beneath them, and that the difference in specific gravity amounts to about 3 per cent. We must now ask how these differences have come about.

Barrell says that originally the fluid earth had a surface as level as that of the ocean. The problem of the origin of the ocean basins and of the continental platforms resolves itself into one of the origin of the density differences in the lithosphere and the maintenance of the heated and weak condition of the asthenosphere. It is thought that the disintegration of the radium-bearing minerals has acted as a permanent generator of heat in the rocks that contain them (see Pt. I, p. 264). Near the surface, this heat is lost through conduction, but that generated within the asthenosphere can not so escape but must slowly transform some of the solid rock into liquid form. In this way, reservoirs of molten rock arise that may melt themselves through to the surface. It is this deepest seated and heaviest magma that, through rising into the lighter subcrust, weights it and thus drags down into basin form parts of the original granitic lithosphere. The forms and relations of the ocean basins suggest that in the earliest times, following the solidification of the earth, such dense molten matter from the depths of the earth broke into or through the outer crust on a gigantic scale, eruption following eruption until the widespread floods of rock had weighted down broad areas and caused them to subside into ocean basins.

As seen in the lava plains of the moon, such an action, once started at a certain point, is conceived to have gone forward with widening radius, leading to the origin of the many rudely circular outlines characteristic of the ocean basins. The process left great angular segments of the original lighter crust as continental platforms standing in relief between the coalescent basins. The waters gathered naturally into the basins and the continents were left standing emerged as elevated areas.

Regional crustal subsidence was especially characteristic of Azoic time, but the process did not cease then. In later chapters we shall see how the same process during the later Paleozoic and Mesozoic continued to break down great lands permanently into the ocean basins.

Source of the Salts of the Oceans. — The composition of ocean waters is discussed on p. 91 of Pt. 1 of this book. As all of this saline matter has been leached out of the rocks of the dry land since the earth has had rains, and as very little of it, comparatively,

has been taken out of the ocean by the accumulating rocks, it has been estimated that it represents the breaking down of a mass of average igneous rock equal to at least 6900 feet in thickness over all the continental platforms. Probably it is more correct to state that the continents have suffered erosion of igneous rocks amounting to between 1 and 2 miles of average depth. Of course all erosion throughout geologic time was far greater, perhaps from 50 to even 100 per cent higher, since it included the reworking of older materials, igneous and sedimentary. Furthermore, "more than a half, perhaps four fifths, of the erosion of igneous rocks was accomplished before the beginning of the Paleozoic" (Barrell).

Eozoic Time

Eozoic time is the final hypothetic interval between the Azoic, when the earth was being prepared as the abode for life, and the Archeozoic, when life is known to have been on the earth.

Evolution of the Primordial Atmosphere. — With the separation of the lands from the oceans, Barrell states, erosion began, carbon dioxide was abstracted from the atmosphere to make carbonates, and a further cause of atmospheric depletion was initiated. Thinner, rarer, and colder grew the gaseous envelope, until an oscillating balance was established between the supplies of new gases from the uprising molten rocks and the loss involved in the weathering of their solid forms. Nitrogen was at first relatively small in quantity and oxygen not present in more than a trace. An evolution in atmospheric composition had still to go forward through the following ages to transform it into a gaseous medium for the support of the higher land-living plants and animals.

Even early in the times following the gathering of the oceans and the emergence of the lands, the sun warmed the atmosphere and the earth. An environment suitable for the original and most primitive life had probably arisen in the oceanic waters of Eozoic time, since very low forms of marine plants, algæ and bacteria, are known in Archeozoic rocks.

The chlorophyl-bearing plants, now as ever, are using the carbon of the carbon dioxide of the air and water and freeing the oxygen. In this way, through plant life, the amount of free oxygen in the atmosphere and hydrosphere has constantly been made. On the other hand, much free oxygen is consumed in the conversion of igneous rocks into other kinds through the weathering processes, and more is lost to the atmosphere through the oxidation of sulphides. The great amount of oxygen in the atmosphere is therefore

entirely due to the dissociation of the carbon dioxide by the green plants.

If all of the water of the oceans and the gaseous emanations of the earth, including the salts and chlorine of the waters and strata, could be put back into the present atmosphere, the pressure, according to Barrell, would be equal to 3756 pounds per square inch at the surface of the earth. It is now 14.7 pounds. This calculation gives some idea of the vast quantity of materials that the earth has belched out of its interior.

In the primordial atmosphere, there must have been but a trace of free oxygen, since the extensive lava flows at the time were consuming it. The ocean waters were then almost fresh and the chlorine was combined with calcium and iron. Oxygen in notable amounts seems not to have been present until some time in the Proterozoic, since it is at this time that the first oxidized or red rocks appear (Animikian formation).

We see accordingly that the first plants must have been such that they could live without free oxygen, and they may have been like the living anærobic bacteria. The photosynthesizing plants of the oceans, however, made free oxygen, and with its existence animal life was possible. Carbonaceous strata occur and beds of graphite are common in the Archeozoic.

Origin of Life. — Life has been propagating life with change (evolution) probably ever since the earth has had a hydrosphere and an atmosphere. How, where, and when it began is geologically unknown, though the theory of its origin has been discussed in Chapter II. We note the presence of life in the Archeozoic, both directly, and indirectly through its chemical action upon the elemental substances, as shown in the accumulation of carbonaceous deposits (black shales, graphite) and iron-ores. Early in the Archeozoic occur limy precipitates of algæ, and later, bacteria, and in the late Proterozoic we meet for the first time with the actual remains of higher animals, radiolarians, sponges, trails and tubes of annelids.

Collateral Reading

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THE CHANGING ASPECT OF NORTH AMERICA, OR THE GEOSYNCLINES, BORDERLANDS, AND GEANTICLINES

One of the greatest truths of Geology is that the continents are continually undergoing change; they are from time to time slightly and irregularly elevated or depressed over more or less extensive areas, while long and narrow tracts toward their margins slowly subside tens of thousands of feet. Later the subsiding tracts rise fairly rapidly into mountains, and these are subsequently vertically reëlevated time and again. Outside of the long and comparatively narrow tracts are rising wide borderlands that furnish the sediments for the shallow seas of the sinking tracts, and that once extended hundreds of miles into the oceans beyond the present shorelines. These crustal movements, along with erosion, were the primary causes for the changing topographic and geographic aspects of North America, which will now be taken up in greater detail.

The unravelling of North American geology and stratigraphy began in earnest with the state survey of Massachusetts in 1830, and that of New York in 1836. During this decade there were organized no fewer than fifteen state surveys and two national ones. In the next twenty years, eleven other surveys came into being, besides the path-finding federal railway surveys across the Rocky Mountains made by Emory, Marcy, Pope, Ives, and Newberry.

The question of mountain origin could not fail to attract the attention of these early pioneers in American geology, and here the path was blazed first by the Rogers brothers and later by James Hall, followed by James D. Dana and Joseph LeConte, the area of their generalizations being chiefly the Appalachian Mountains. As early as 1842, the Rogerses offered an explanation, not only for the structure of the Appalachians but for their causes as well, though their ideas were not published in detail until 1857, when they were embodied in the epochal *Final Reports on Pennsylvania.*

Geosynclines

(Study Figs., pp. 139 and 159)

As a result of the work in the Appalachians of Pennsylvania and Virginia, in the valley of the St. Lawrence, and in New York,

James Hall came to see that mountains occur only in areas of greatest sedimentary accumulation, and never where formations are thin. For example, the Paleozoic formations in the Appalachian region are possibly ten times and certainly six times thicker than the equivalent deposits of the same seas in the Mississippi Valley. These thick sediments we now know were accumulated in narrow troughs or synclines that persisted as shallow seaways for long periods of geologic time. Such troughs were unstable areas of the earth's crust, sometimes subsiding and sometimes rising until their great thicknesses of sediments were folded into mountains. In other words, as Hall saw, mountains arise out of the very areas that previously had long been seaways or synclines of subsidence and sedimentation. His term "synclines" for these long narrow areas was altered by Dana to *geosynclines*, since they do not have the simple syncline structure, but are made up rather of many true or simple synclinals as well as anticlinals. The mountain system that eventually rises out of a geosyncline, Dana at the same time called a *synclinorium*. Synclinorial mountains arise subsequently out of the strata of a geosyncline, through folding due to lateral compression, following upon a shrinking earth. See also Pt. I, pp. 304–306, 380, 385, and 396.

Since the time of Hall and Dana, North American stratigraphy has made much progress, and we now know that early in Proterozoic time there were in existence three geosynclines: (1) the *Appalachic*, in the eastern part, trending northeast-southwest; (2) the *Cordilleric*, in the west, with a north-south axis; and (3) the *Ontaric*, in the medial part of the continent, striking nearly east and west. The last-named was folded into mountains at the close of the Proterozoic. These troughs need not here be described further, since this will be done later on. The student should from time to time consult the figures on pages 139 and 159, so as to impress upon his mind the geographic position of the geosynclines and lands.

In the Paleozoic era there were four geosynclines: (1) *Appalachic*, and (2) *Cordilleric*, as before; (3) *Acadic*, in sympathetic relation with Appalachic; and (4) *Franklinic* in the American Arctic regions, with a northeast-southwest trend. The northern half of the Appalachic geosyncline (= St. Lawrencic trough), and all of the Acadic geosyncline were converted into mountains toward the close of the Devonian, while the Franklinic and the southern half of the Appalachic rose into mountains toward the close of the Paleozoic. Therefore of the Paleozoic geosynclines only the Cordilleric continued into the Mesozoic.

PLATE 1. — Pioneers in the theory of mountain building out of geosynclines

Fig. 1. — James Hall (1811–1898). Father of the theory of geosynclines. Fig. 2. — James D. Dana (1813–1895). Professor of Geology at Yale. The first to put into working order the theory of mountain building out of geosynclines.

Fig. 3. — Henry D. Rogers (1808–1866). State Geologist of New Jersey and Pennsylvania. One of the first to unravel the Appalachian structure. Fig. 4. — Joseph LeConte (1823–1901). Professor of Natural History at the University of California. Expounder of Dana's theory. A great lover of the Sierra Nevadas.

In Mesozoic time there developed out of the great Cordilleric geosyncline a long and narrow land, the Central Cordilleran geanticline (see p. 141). Then during the Cretaceous there lay (1) to the east of this land the recently developed vast *Rocky Mountain geosyncline*, and (2) to the west of it the smaller *Pacific geosyncline.* Finally, at the close of the Mesozoic the former trough was folded into the Rocky Mountains, while a southern part of the Pacific geosyncline continued as such into Cenozoic time.

Embayments. — The geosynclines also often had great connecting bays called embayments, which usually endured during the existence of the geosynclines. Prominent among them were (1) the *Ouachitic embayment,* trending east-west across Arkansas and Oklahoma; (2) the *Sonoric embayment,* also extending east-west through northwestern Mexico into Texas; and (3) the *Alexandric embayment* of southeastern Alaska. Finally (4) the *Northumberlandic embayment* was a post-Devonian seaway between the mountains of Acadis. All of these embayments were of Paleozoic time, though the Alexandric one continued throughout the Mesozoic.

Borderlands

(Study Fig., p. 139)

Borderlands are situated outside or oceanward of the geosynclines, and are periodically raised into highlands, though they never appear to have been folded while the troughs on their inner sides were subsiding. They may have been faulted and tangentially sliced and thrusted toward the geosynclines while the troughs were subsiding, but this action appears to have taken place mostly during the times when the geosynclines were being folded into mountains. Because the borderlands are periodically raised, they are the regions from which most of the clastics have been derived and delivered into the geosynclines.

The borderlands formerly extended an unknown distance out into the oceans. From the quantity of sediments that they have furnished to the geosynclines, it is certain that they continued beyond the present strandlines at least 200 to 300 miles, and some of them doubtless considerably farther. Their geologic histories are as yet but little known, but the quantity and nature of the clastics derived from them indicate their extent, the times of their periodic elevation, and that they were composed essentially of crystalline rocks, and mainly of granites.

North America is margined on the east by the borderlands *Acadis, Appalachis,* and *Antillis,* each one of which has its own geologic

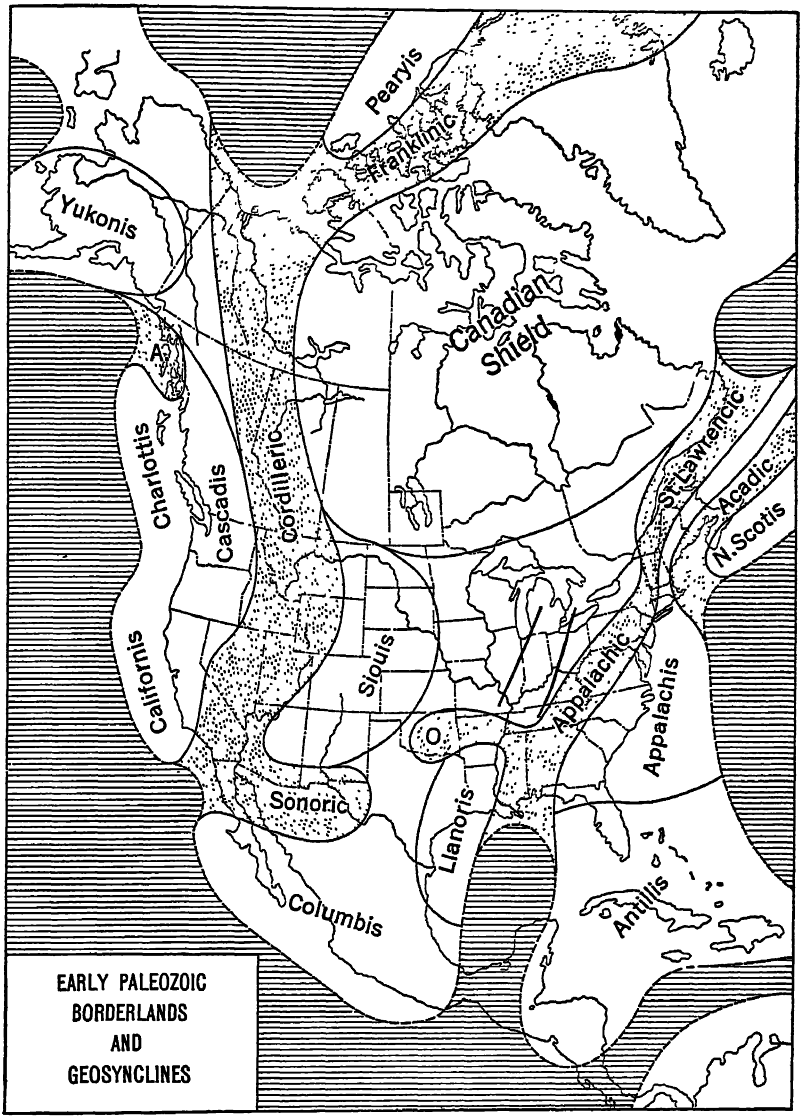

Fig. 39. — The North American borderlands, geosynclines, and medial or neutral area (Canadian Shield and Siouis) of earlier Paleozoic time (Cambrian to close of Devonian). A, Alexandric embayment; O, Ouachitic embayment. The same relations of seas and lands are continued throughout later Paleozoic time, except for the absence of the St. Lawrencic and Acadic geosynclines. A part of the Acadic area is then occupied by the Northumberlandic embayment. The black line through Ohio is the axis of the Cincinnati geanticline, and the one through Illinois the Kankakee axis. Also see Fig., p. 159.

structure and history, though almost nothing is known of the history of Antillis. Along the west coast is the greatest of all borderlands, *Cascadis*, which later on divides into *Californis* and *Charlottis*. Mexico, or *Columbis*, appears to be an old nucleus, while its northeastern extension *Llanoris* is the borderland of the Ouachitic embayment. Finally, Arctic America is bordered by *Pearyis*, part of which is now elevated, along with the Franklinic geosyncline, into the folded United States Mountains.

Geanticlines

(Study Fig., p. 141)

The term geanticline was proposed by Dana in 1873 for "the upward bendings in the oscillations of the earth's crust — the geanticlinal waves or anticlinoria." His typical example was the Cincinnati arch, though later on he also included (under the term anticlinoria) far greater and even continental (epeirogenic) arching. Beginning with simple, depressed, and restricted arches, the term therefore came to be applied to all archings of lesser or greater extent.

Geanticlines and geosynclines are complementary flexures of the lithosphere, and the regularly folded, faulted, and thrusted outer part of the lithosphere, where these structures can be easily made, is known as the *tectonosphere*. In the area of the oldest mountains, where all of the tectonosphere has been worn away, as in the Lake Superior-Ontario-Quebec regions, one gets to see the originally deeper zone of rock flowage and granite bathylithic intrusions. These structures of the deeper lithosphere are very difficult to interpret correctly.

Of geanticlines, the best known ones are the following: The *Cincinnati geanticline* was defined by Dana in 1890 as the wide flexure in the lithosphere centering near Cincinnati, Ohio, and Nashville, Tennessee. Its width is something like 250 miles. It has in a general way the strike of the Appalachian folds, and was at times completely overlapped by the interior epeiric seas. The uplift began in middle Champlainian time, was followed by repeated reëlevation, and during the middle and late Paleozoic the region continued as a low ridge or as islands in the eastern inland seas.

The *New Brunswick geanticline* was in existence very early in the Paleozoic and continued up to the close of the Devonian as the highland between the Acadic and St. Lawrencic geosynclines. It includes the granitic area of eastern Connecticut and Rhode Island and the White Mountains of New Hampshire, and strikes

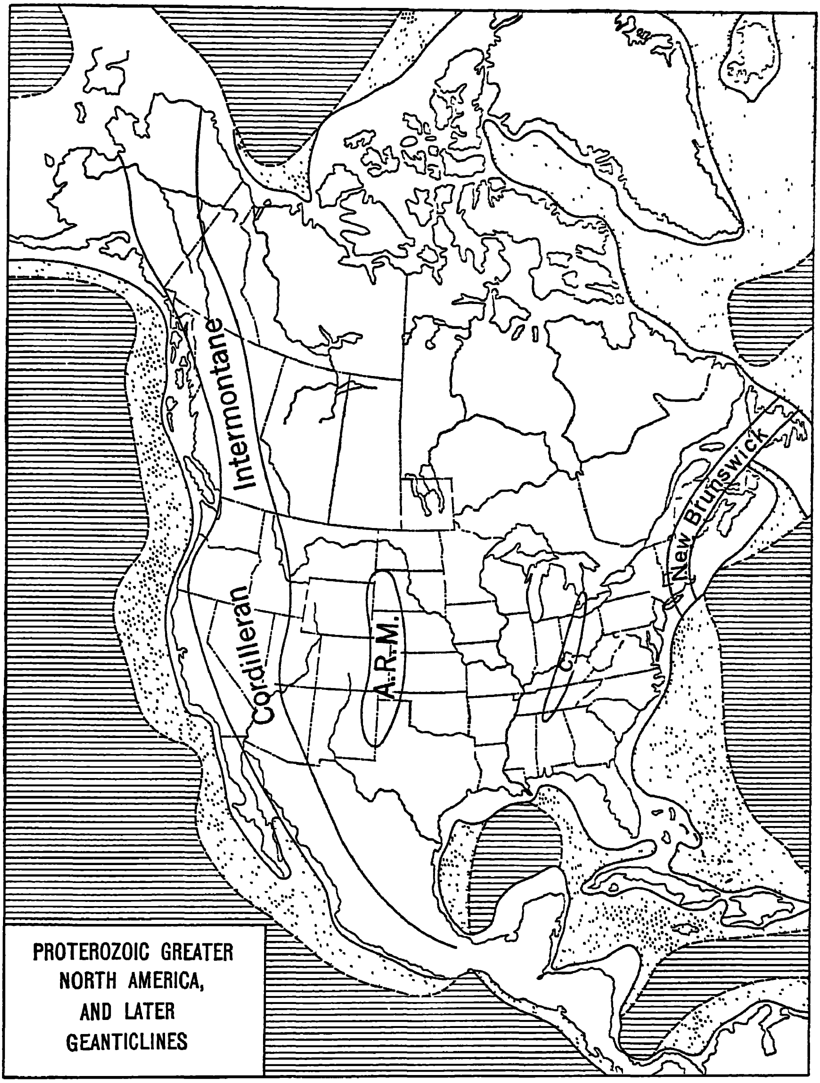

Fig. 40.—Greater North America during the earlier Proterozoic (shown by the dotted areas), to bring out the amount of land thought to have since foundered permanently into the oceanic basins, amounting to about 2,000,000 square miles. This map also shows the four geanticlines of North America. C, Cincinnati geanticline; A. R. M., Ancestral Rocky Mountains geanticline.

across central Maine into northern New Brunswick and southern Newfoundland. Its present width averages more than 100 miles.

The *Ancestral Rocky Mountains geanticline* described by Lee arose late in the Paleozoic across eastern Colorado and New Mexico, western Kansas and Oklahoma, and northwestern Texas. To the west of it lay the Cordilleric seas of late Pennsylvanian and Permian times, while to the east of it were the brackish-water Mississippian seas of the same periods. These mountains were base-leveled in early Jurassic time, since late in this period and during the Cretaceous the Rocky Mountain sea completely transgressed the roots of this geanticline. A part of it is the present reëlevated Front Range (Long's and Pike's peaks) of Colorado.

Most extensive of all the geanticlines was the *Central Cordilleran* (in Fig. 40 called *Cordilleran Intermontane*), extending from Alaska into Central America. To the east of it was the vast Rocky Mountain geosyncline, and to the west the smaller Pacific inland seas. This, the greatest geanticline of North America, began to appear in Nevada, Utah, and Idaho certainly as early as the late Triassic, and at the close of the Jurassic was completed into Alaska. This old arched land exists to-day as the elevated plateaus known as the Northern Interior, Columbia, and Nevada-Sonoran.

Collateral Reading

C. Schuchert, Sites and Nature of the North American Geosynclines. Bulletin of the Geological Society of America, Vol. 34, 1923, pp. 151–230.

CHAPTER XI

THE ARCHEOZOIC ERA

History of Classifications

The greater part of Canada, or, rather, the Canadian Shield, of over 2,000,000 square miles in extent, exposes the oldest portion of the North American continent (see Fig., p. 139). Here lies the very complex record of event upon event, made during the earliest eras of geologic time.

Work of Sir William Logan. — The beginning of the unraveling of this history fell to William Edmond Logan (1798–1875), the first director of the Geological Survey of Canada. He did his pioneer work well, and, as he inaugurated the study of pre-Cambrian formations, he has been called the Father of Pre-Cambrian Geology.

Fig. 41. — Sir William Logan (1798–1875). Pioneer Canadian geologist, and Father of Pre-Cambrian Geology.

Geikie says of Sir William Logan: "At the very beginning of his connection with the Geological Survey of Canada in 1843, Logan confirmed the observation [of previous geologists] that the oldest fossiliferous formations of North America lie unconformably on a vast series of gneisses and other crystalline rocks, to which he continued at first to apply the old term Primary." After years of labor on the part of himself and his associates, "he proposed for these most ancient mineral masses the general appellation of Laurentian, from their development among the Laurentide mountains. . . . In the course of his progress, he came upon a series of hard slates and conglomerates, containing pebbles and boulders of

the gneiss, and evidently of more recent origin. . . . These rocks, being extensively displayed along the northern shores of Lake Huron, he named Huronian. He afterwards described a second series of copper-bearing rocks lying unconformably on the Huronian rocks of Lake Superior. He thus recognized the existence of at least three vast systems older than the oldest fossiliferous formations. . . . He will ever stand forward as one of the pioneers of geology, who in the face of incredible difficulties, first opened the way toward a comprehension of the oldest rocks of the crust of the earth."

Method of Correlation. — In deciphering the pre-Cambrian chronology the geologist has no fossils to depend upon, and the criteria used in the working out of the geologic sequence are of a physical nature, as follows: (1) similarity of rock character, (2) structural nature of the rocks, (3) superposition of the formations, (4) crustal movements, and (5) cycles of erosion. The study of the various pre-Cambrian formations makes it clear that their two most significant and distinctive features are: (1) the wide-spread crustal revolutions, characterized by vast upwellings of molten rocks; and (2) the profound depth to which erosion has planed, revealing over great areas deeper levels of the crust which, while deeply buried, were subjected to regional metamorphism — levels whose original place was miles beneath the present surface.

Length of Pre-Cambrian Time. — It is generally admitted by geologists that the time back of the Cambrian, the first period with an abundance of fossils, was extremely long. There were during this time at least two and possibly three marked revolutions, and how many smaller breaks there are in the geologic record no one has the faintest knowledge. In consequence, we have allotted, on the basis of the radioactive clock (see Fig., p. 105), more than one half of geologic time to the Archeozoic and Proterozoic eras.

Terminology. — In regard to the use of the terms Archeozoic and Proterozoic for the Age of Larval Life and the Age of Primitive Invertebrates, respectively, the following should be stated. As the subsequent eras are marked by an abundance of life preserved as fossils, it is highly desirable to bring out this fact in the names through the ending *zoic,* which means *life.* Previous to the eras with an abundance of fossils, the older ones have almost none in recognizable forms, and at best they are always exceedingly rare. Therefore a classification of the formations of the Proterozoic and Archeozoic on the basis of fossils can not be developed, though it is certain that life existed throughout both of these eras. The usage of *zoic* in the names of these eras is, however, justifiable, and har-

monizes them with those used for the later eras, even though the classification of the Archeozoic and Proterozoic formations is by geologic structure and not by fossils. Since the formations of the Archeozoic are seemingly devoid of fossils and in addition very greatly altered, some geologists prefer to call it Archean (means very old or may be taken to mean beginning), a term once applied to all pre-Cambrian formations. In this book, however, Archeozoic is preferred because it means *oldest* or *primal life*, a significance in harmony with our present conception.

Divisions of Archeozoic Time. — In Chapter VII, the geologic events of pre-Cambrian time are given in tabular form and in relation to the younger formations; below, only the more important events of the Archeozoic are listed, arranged from younger to older.

Table of Archeozoic Events

Ep-Archeozoic Interval and peneplanation	
Diastrophic record	Laurentian Revolution, mountain making, and intrusion of Laurentian granites
Aqueous and volcanic record	?Grenville series (may prove to be Proterozoic (Huronian)) Keewatin-Coutchiching volcanics and sediments
Unrecoverable beginning of earth history	

Archeozoic Time

In Chapter IX were described the events that are thought to have taken place during pre-Archeozoic time, and now we will proceed to a presentation of the oldest formations known to geologists.

Basement Complex. — The student of Archeozoic rocks is confronted with vast difficulties, since none of the formations of the basement complex are in their original condition. They are called basement rocks because they are the oldest known, and a complex because of their highly altered present natures. The water-laid sediments and the lavas and granites have been greatly altered through tremendous pressures of mountain-making forces, and bent and gnarled by intruded igneous masses. Hence their original condition has through heat, pressure, and consequent rock-flowage been caused to undergo chemical change, and its mineral matter has recrystallized into other kinds, resulting in new rocks that are in a crystalline, gneissic, or schistose condition. At many localities nothing remains as it was, all appears to be in hopeless confusion, and therefore the order of superposition of the formations, and the time value to be placed upon their contacts, are exceedingly difficult

to establish. Greatest value is now placed on the degree to which younger eruptives welling up from below have cut the older formations, since the age of an eruptive rock is reckoned from the time when it cooled in the intruded masses. Next in value is the areal extent of the angular unconformities resulting from mountain making and from the later long-continued erosion intervals.

The Archeozoic, as a whole, is homogeneous in its heterogeneity, that is, it is alike in its extraordinary complexity.

First Sedimentary Rocks. — In the earliest but as yet undiscovered geologic history, the surface of the earth is thought to have had igneous rocks only, and these essentially granites. With the appearance of rains came the first sediments, the erosion products of granites and lavas, besides volcanic dust and solution materials like limestones dissolved out of the granites and lavas. The sediments must therefore have been sandstones and mudstones, and the limestones may at first have been precipitated chemically; later on, organisms took part in their deposition.

Absence of Original Earth's Crust. — Geologists have as yet no evidence as to what took place in earliest Archeozoic time, nor have they seen the original foundation upon which the Coutchiching, Keewatin, and Grenville series rest. The evidence, therefore, is positive that the former foundation of the Canadian Shield, that is, the rocks older than those now resting upon the Laurentian granites, has been displaced or re-fused by the great upwellings of these, the most ancient of known granite rocks.

Archeozoic Formations. — The Keewatin and the Coutchiching are the oldest known formations of North America. The *Coutchiching formation* is the oldest series of sedimentaries known and occurs typically in the Rainy Lake country of Canada north of Minnesota. Its thickness at the very least is 4600 feet, and it originally consisted mainly of carbonaceous shales, now metamorphosed into mica-schists, and dolomite, both probably of marine origin. The *Keewatin*, best known in the Lake of the Woods area of extreme western Ontario, consists of subaqueous dark lava flows (usually basalts, now greenstones or schists), with some ash beds and black carbonaceous and sandy mudstones, now changed to schists. Farther east, as at Hunter's Island and the Mattawin River, there is much iron (usually hematite) in banded jaspers, and the iron is mined in the Vermilion Range of Minnesota. The Keewatin, like the succeeding Grenville, has a wide distribution, but the outcrops are generally small and much localized. It represents one of the greatest outpourings of basalt.

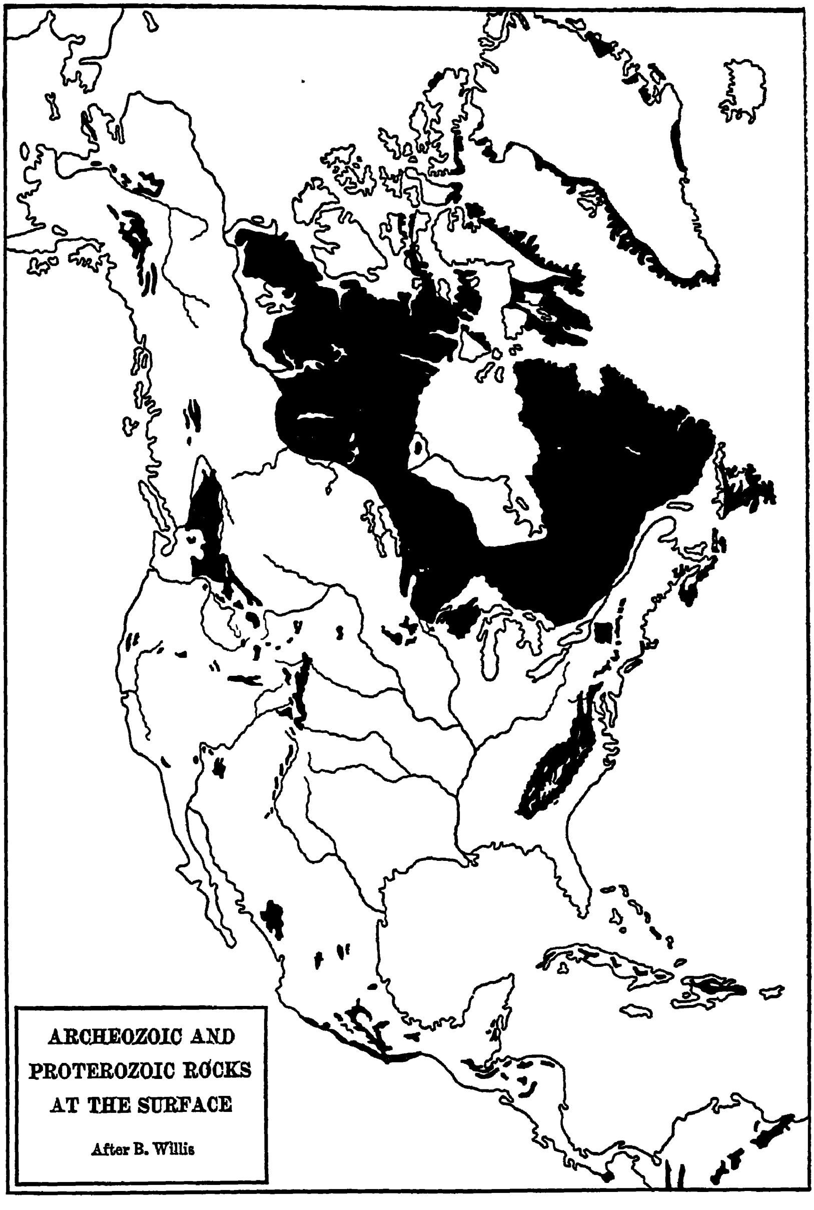

Fig. 42. — The surface distribution, in black, of the undifferentiated Archeozoic and Proterozoic formations. B. Willis, U. S. Geol. Surv. Also see the geological map at the end of this book.

In the Province of Ontario north of Lake Ontario and east of Lake Huron, occurs a vast succession of essentially calcareous strata, the thick *Grenville series.* These formations are in this book retained in the Archeozoic in conformity with the prevalent opinion, though Leith and Collins think they may be of Proterozoic (Huronian) time. We were first made acquainted with this series by Logan, who gave the rocks their name from Grenville township. They are now known to cover most of Labrador, Quebec, Ontario, the Thousand Islands, the Adirondacks, and southern Baffin Land. Adams and Barlow have estimated the thickness in Ontario as over 94,000 feet (nearly 18 miles), of which about 50,000 feet is limestone. The limestone phase is, however, practically limited to southern Ontario, the Adirondacks, and Quebec. (See Fig., p. 147).

The most striking parts of the Grenville series are crystalline limestone, sometimes a coarse white marble but more often colored. It abounds in graphite, mica, hornblende, and serpentine. As it weathers easily, it is commonly found in valleys or along lakes. Associated with the limestone is gneiss, and in lesser amounts quartzites; these originally were mudstones and sandstones. Beneath the Grenville occur old lava flows suggesting those of the Keewatin.

Grenville rocks usually extend over the ground as long bands between areas of gneissic granites, since they commonly form steeply dipping synclinal troughs caught between the bathyliths of the Laurentian gneiss. These banded structures are due to the strata having been domed by the rising bathyliths of the Laurentian mountains, which are now so deeply eroded across as to expose only their roots, the deeper parts of the Grenville synclines, between which are the granite domes. (Coleman and Parks.)

Serpentine is common in the Grenville marbles, and here are found the fossil-like structures known as *Eozoön,* described on a later page. The Grenville is the thickest known series of Archeozoic strata and appears to be the deposits of a transgressing shallow warm-water sea. It is probably in part a chemical and in part a bacterial deposition. Toward Hudson Bay the limestones vanish and give way to what were originally muds and sands and are now quartzites, gneiss, and schists (Cooke 1919).

Because of the shallowness of the Grenville seas, and because their muds and sands came from the Hudson Bay region, Cooke points out that *a great part of the Canadian Shield was already present in Grenville time* as a positive or continental element. This

shows how far back in geologic time the rocks of this shield originated, and that the nucleus of North America probably came into existence during the formation of the earth's original crust.

In the Grand Canyon of the Colorado (see Frontispiece) the Archeozoic rocks are known as the *Vishnu series.* Here the Granite Gorge of the river exposes these rocks for 40 miles. They consist of gneiss (50 per cent), mica-schists (30 per cent, the metamorphosed sediments), basic intrusives (10 per cent), and pink siliceous intrusives. It may be that here occurs an ancient gneiss basement on which the schists were deposited (Noble 1916).

Graphite. — The attention of geologists has long been attracted to the great quantity of graphite in the Archeozoic strata, chiefly in the quartzite-schists. Sir William Dawson long ago said there was more graphite disseminated in the Grenville series than there is carbonaceous matter in the entire Carboniferous (coal-bearing) systems. Bastin states that in the Adirondacks the graphite varies from 3 to 10 per cent by weight of the rock. Near Hague, on Lake George, New York, occur alternating layers of graphitic schists from 3 to 13 feet thick, and the appearance is that of a fossil coal-bed. This graphite is believed to have been derived in the main from carbonaceous or bituminous shales, of organic origin, and probably the residuum of primitive marine plants.

Quebec Geosyncline. — From Labrador to Lake Superior, through a distance of more than 1400 miles, there extended along the southern side of the Canadian Shield in Archeozoic time the great Quebec geosyncline (so named because a greater part lay in the Province of Quebec), apparently deeper in the northeast than in the southwest. In general, the strike of the formations laid down in this trough is between N. 75° E. and S. 70° E. Along the southern side of the trough east of Lake Huron occurs the very thick Grenville series of limestones, which becomes more and more metamorphosed, folded, crumpled, and elevated to the north. Toward the close of the Archeozoic, a long northeasterly-southwesterly trending mass of granite, having the general direction of the present north shore of the St. Lawrence River, and followed on the north, not by limestones, but by sandstones and conglomerates (Cooke), broke through the sediments of the trough, resulting in the formation of the Laurentian mountains. Then early in the Proterozoic there was developed out of the area of the former trough the later ("sequent") Ontaric trough to be described in the next chapter. (See Fig., p. 159.)

Archeozoic Mountain Making and Laurentian Peneplain

Laurentian Granite. — The chief rock formation of the Canadian Shield is the widely distributed Laurentian gneiss and granite. It is the consolidation of numberless bathyliths that have welled up as molten magma into the older sediments known as the Keewatin series in the Lake Superior country, and eastward in Ontario as the Grenville series. So prevalent are these granites that they cover more than 90 per cent of the Lake Superior country, and for a long time were regarded as the original cooled surface, or crust, of the earth, upon which the above-mentioned formations rest. Since 1887, however, it has become clear that these granites are not older than the formations they seem to underlie, but that they are really younger, for they have upwelled from unknown depths of the earth, have broken up the older rocks, and shattered and invaded the formations above them. Geologists, therefore, do not as yet know upon what foundation these older invaded formations lie, and it has been said that they "rest upon nothing." Although, from the standpoint of their origin, they do rest upon nothing known, in actual superposition they rest or float upon the Laurentian granites. However, it should not be forgotten by the student that these basement granites are intrusives and therefore younger in age than the Keewatin and Grenville series, which rest upon them.

The Laurentian rocks are mainly "granite, granodiorite, or syenite, with smaller amounts of gabbro or diorite; but usually these materials have a schistose or banded structure and are termed gneiss. The rocks are mostly coarse-grained and often contain porphyritic feldspar crystals, and, in many cases, they have been sheared into 'porphyritic granitoid gneiss,' a very common phase of the Laurentian.

"Laurentian batholiths are often oval, but sometimes irregular in shape where several upwellings have combined, and have a schistose structure parallel to the curving edge, changing inwards to the ordinary structure of granite. They may be of all sizes, from a few miles to fifty miles in longest diameter, as on Rainy lake; and their general arrangement runs roughly north-east (50°–80° east of north), indicating the direction of the great mountain chains of which they formed the cores" (Coleman and Parks).

Ep-Archeozoic Interval. — After an exceedingly long era of seemingly tranquil events and the accumulation of vast depths of marine and some continental deposits, Archeozoic time in the southern area of the Canadian Shield passed into the throes of the Laurentian mountains, as described in treating of the Laurentian granites. Then followed a long time of erosion, the Ep-Archeozoic Interval, reducing the highlands to a peneplain (see p. 145). This

erosion interval is the most significant break in all North American geology, and the Canadian Shield the most remarkable of all known peneplains.

> "The hills are shadows, and they flow
> From form to form and nothing stands;
> They melt like mists, the solid lands,
> Like clouds they shape themselves and go."
>
> *Tennyson.*

Present Character of the Canadian Shield. — The greater part of the present surface of the Canadian Shield (see map, p. 139) is an undulating plain replete with an intricate series of connected lakes and rivers (Fig., below); near the center of it lies a depressed

Fig. 43. — Laurentian peneplain as seen from Lake Michikamau, Labrador. Photograph by A. P. Low. Yale University Press.

area containing Hudson Bay, an epeiric sea with an average depth of 420 feet. From this central basin there is an upward slope in all directions toward the Height of Land. The general level of the plain above the sea is about 1500 feet, and the local differences of level are usually under 150 feet, though rarely they may be as much as 500 feet above the general plain.

The peneplain of the shield as a whole rises slowly to the east, and in central Ungava is about 2400 feet above the sea. Along the eastern margin of Labrador are rugged mountains that in the north attain 6000 feet, and certain peaks even reach 7500 feet. In fact, it may be said that a mountainous tract extends for 2000 miles from Belle Isle north to Cape Sabine in Ellesmere Land. This rough topography, and also that along the southern margin east of

the city of Quebec, is youthful in form, and the deformation of the shield here is thought to have arisen in early Pleistocene time, the movements continuing to recent times.

Suess would limit the shield to Canada, as above defined, but Adams and other geologists include in it Greenland and the Adirondacks of New York. The latter region now reaches a height on a few mountain peaks of about 5000 feet above the sea, the average elevation being about 2000 feet, an altitude which is also the result of Cenozoic upheaval of a regional character.

Evidence of Life in the Archeozoic

The direct evidence that life existed in Archeozoic time is exceedingly scanty, and yet it indicates positively that at least micro-

Fig. 44. — Blue-green alga related to modern *Inactis* or *Microcoleus*. From an Archeozoic pebble in the Ogishke conglomerate, Minnesota. Photograph, × 190, by J. W. Gruner.

scopic blue-green algæ related to modern *Inactis* or *Microcoleus* were living in the era (Gruner 1923, see figure above).

Long ago Sir William Dawson described from the Grenville limestones *Eozoön canadense,* which means " dawn animal of Canada." For a time many accepted these globular masses, sometimes several feet in diameter, as of organic origin, and they have figured in many text-books as such since 1864, though no one successfully showed to what class of animals they belonged. They look very much like Fig. 54, p. 176. They certainly are not protozoan animals as assumed by Dawson. These masses consist of irregularly alternating thin calcite bands and dark green layers, usually of serpentine, and result from metamorphism of the lime deposits. They are now regarded as probably of organic origin and are thought to be calcareous depositions, made involuntarily by marine plants (algæ), i.e., through the chemical reactions of living material (metabolism).

The usual absence of fossils in the Archeozoic does not disprove the theory that life began in soft-bodied microcosms, rather is it indirect evidence confirming the theory. Primordial life, to judge on the basis of the growth stages of things alive now, was too perishable and minute to be preserved as fossils. Lane has therefore called Archeozoic time the *Collozoic Age*, meaning that then the organisms were jelly-like.

The indirect evidence is even more in favor of the view that life abounded in the Archeozoic. This is shown by the nature of the hydrosphere and more especially by the presence of oxygen in the atmosphere and its reaction on the sediments. Another indirect proof is seen in the wide-spread and vast amount of *graphite* in these oldest sediments. This graphite is largely if not wholly the metamorphosed carbon once in organic bodies, and is therefore clear evidence for the presence of life and free oxygen in the atmosphere. These matters are discussed on later pages of this chapter.

The Life-giving Primordial Atmosphere and Hydrosphere. — In the previous paragraphs was given the direct and indirect evidence of life in the Archeozoic, and now we will take up a study of the nature of the primordial atmosphere and hydrosphere and see how they evolved into the present ones. The following is in the main after Barrell.

The heavy acidic atmosphere discussed in an earlier chapter attacked the cooling crust of the earth chemically when it became sufficiently cold, and then oceanic basins became laden with solutions, not only of carbonates, but as well of chlorides of sodium, magnesium, calcium, and iron, because of the large amount of chlorine present. While the chloride solutions continued to accumulate, the carbonates of calcium and magnesium were being chemically deposited as limestones and dolomites. Where sodium silicate was emanating from the earth's interior, its reaction with the chloride of iron resulted in exchanging the iron for the sodium, forming sodium chloride and iron silicate. The latter, precipitating along with the carbonates of calcium and magnesium, Van Hise and Leith (1911) believe gave rise to the cherty iron carbonate formations so common in the pre-Cambrian.

Since oxygen, which is one of the essential constituents of the present atmosphere and the energizing element of animal life, was absent from the primal atmosphere, we must now examine into its source, and as well into the time when the amount of this very important gas became large. Its only known source is in the carbon dioxide of the hydrosphere and atmosphere when freed through the agency of the life processes of assimilating green plants, which take in the CO_2, keep the C, and exhale the O. However, the freed oxygen would not remain in the atmosphere unless the carbon of the plants became buried and excluded from the oxidizing influences of the hydrosphere and atmosphere. Therefore the dead decomposing plants must be buried under muds or their own mass. That this process went on already early in the Archeozoic is attested by the great amount of graphite in the Grenville limestones. The amount of carbon thus locked up as graphite or disseminated in the dark sediments is

PLATE 2. — The probable life of the Archeozoic is inferred from the embryology of the more primitive water-inhabiting life of the present, which repeats during its earliest growth something of its ancestral history. More detail in regard to the progressive evolution of life during the Archeozoic is given on pages 156–157.

Figs. 1–3. — Three forms of bacteria (1, *Pseudomonas;* 2, *Microspira;* 3, *Spirillum*).

4–5. — Lime-secreting algæ or rhabdospheres.

6–9. — Protozoa (6, Flagellata (*Peranema*); 7, colony of Choanoflagellata (*Codosigna*); 8, Ciliata (*Stylonychia*); 9, Dinoflagellata or peridineans).

10–12. — Stages of growth in primitive sponges (10, amphiblastula of *Grantia;* 11, gastrula of *Sycandra;* 12, the full-grown sponge *Sycandra*, × 1/2).

13–16. — Stages of growth in a tubularian hydroid (13, planula-like larva; 14, larva with tentacles; 15, crawling actinula; 16, mature anchored individual).

17. — The fixed strobilla larva that develops into the medusa *Aurelia* (Fig. 19). Figs. 18 and 20 are other medusæ or swimming bells (*Æquorea* and *Tima*).

21. — Two small actinians (*Anemonia*) growing on seaweed.

22. — Free larva of an actinian before fixation (*Urticina*).

23–28. — Trochophora and trochophore-like larvæ (23, trochophore of the gastropod *Patella;* 24, same of the annelid worm *Polygordius;* 25, larva of the brachiopod *Terebratulina;* 26, pilidium larva of a nemertine worm; 27, dipleurula larva of the crinid *Antedon*; 28, tornaria larva of the ancestral chordate *Balanoglossus*).

29–30. — Ctenophora or paddling bells, to illustrate the probable appearance of the Protocœlomata (29, *Beroe;* 30, *Idyia*).

Most of the figures have been copied from E. W. MacBride's *Text-book of Embryology.*

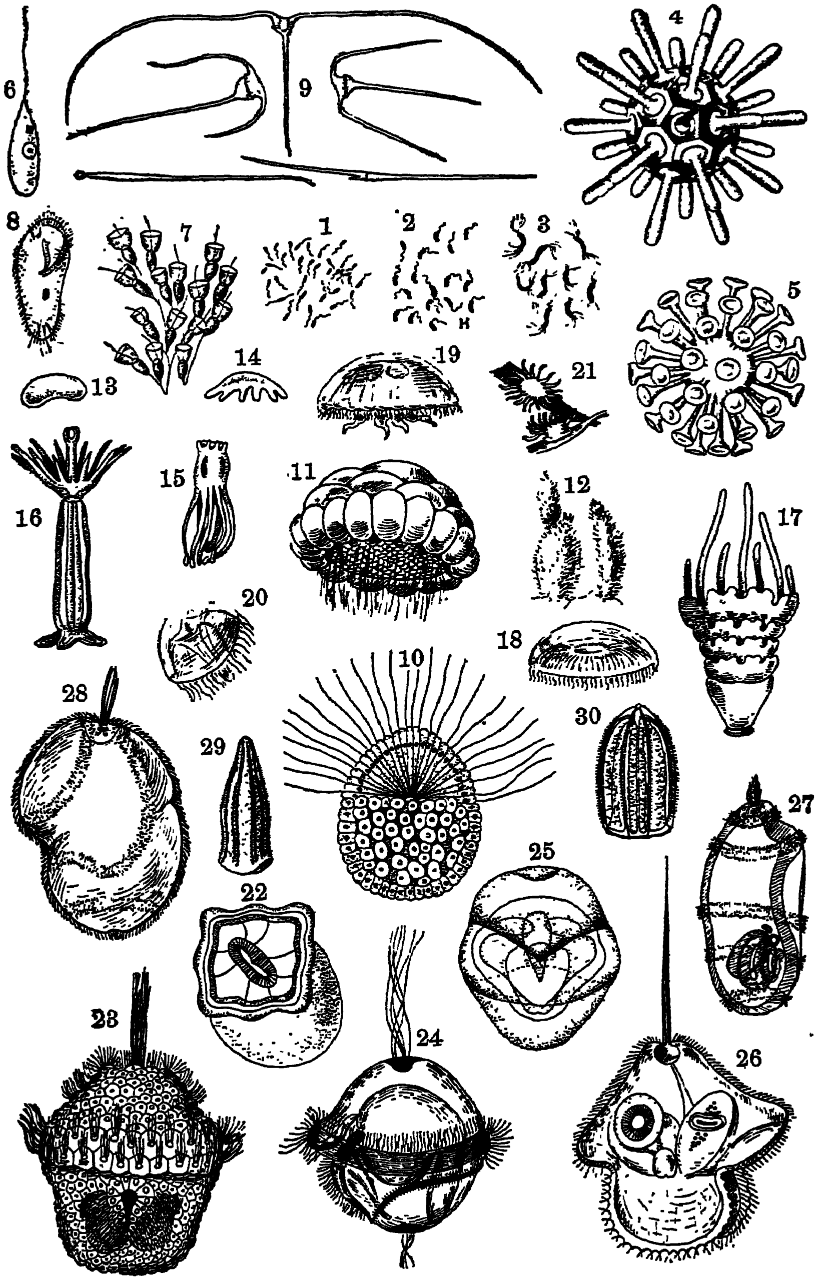

Plate 2

Adults and larvæ of living things suggestive of the probable life of the Archeozoic seas. Nearly all of this hypothetic life was microscopic in size, short-lived, and pelagic in habit, that is, it floated and drifted, or swam but poorly, near the surface of the marine waters. The kinds illustrated in Figs. 12, 16–21, and 29–30 may have attained diameters easily seen by the unassisted eye. Figs. 1–9, 12, 16, 18–21, 29

a measure of the free oxygen that has been added to the air and waters throughout geologic time. Therefore the oldest carbonaceous deposits or the graphite that has resulted from their metamorphoses give clear evidence of the earliest presence of life and of free oxygen.

The first clear evidence of an atmosphere rich in free oxygen is proved by the Archeozoic hematite of the Vermilion district, and especially by the red color of Proterozoic strata. In the absence of free oxygen, the iron of sediments must be deposited as a ferrous salt which can give them only gray or green colors, but in the presence of free oxygen the iron may be oxidized to a ferric state, when the deposits take on yellow, red, or brown colors. The oldest Archeozoic sediments are dark or gray in color, but the continental deposits of Proterozoic time are often oxidized into red colors. From this evidence is gathered the conclusion that in Archeozoic time the weathering of the enormous areas of basic rocks used up the free oxygen about as fast as it was being liberated by the assimilating plants. It is clear, therefore, that the weathering of all geologic time has abstracted from the atmosphere many times more free oxygen than it now contains.

It further appears from what has been said that primordial life must have been more or less like the anærobic bacteria, which can live without free oxygen, and probably can tolerate carbon monoxide.

In the later Proterozoic (Beltian), we see an abundance of red fresh-water sediments, proving that then the atmosphere was rich in free oxygen. Furthermore, the Animikian formations of the Proterozoic are very rich in carbonaceous deposits, and in the Beltian formations there are animal remains as complicated in structure as the tube-inhabiting annelids.

For a time the primal oceanic waters were almost fresh, and, as Lane believes, probably tending toward being acid. Under such conditions no organism could directly secrete hard parts until the concentration of salts reached and passed the optimum for some cell activity, when the extra lime would be secreted as a pathologic reaction. The geologic evidence tends to show that throughout the Archeozoic organisms did not directly use calcium or silica. The earliest external skeletons of both plants and animals were nitrogenous, and later some became siliceous and more calcareous.

Probable Life of Archeozoic Time (see Pl., p. 155). — Since it is now known that algæ and bacteria existed late in the Archeozoic, we may conclude from the presence of much graphite and the further evidence of the nature of the sediments themselves, that there was then an abundance of life. It is in order, therefore, to speculate as to the probable forms and stage of evolution attained by the organisms of the Archeozoic. Furthermore, since late in the succeeding era there is the added evidence of annelid tubes, we are all the more justified in holding that considerable organic progress had been made in this early era.

In our theorizing about the kinds of this life, we may take as a safe guide the embryology of the living world, all of which, plants and animals alike, starts in a single or in a fructified cell, and each living individual recapitulates the development of the race. Therefore it is believed that for a long time the oceanic waters must have been peopled by a great variety of exceedingly minute floating plants, whose whole organization was in a spherical cell, and which were of a green or red color. They were living on the carbon dioxide and nitrogen of the water, their home. Their abundance soon led to congregation and to parasitism, to communal cell life and to feeding upon one another, and so gave rise to the

animal kingdom. Survival was facilitated first by attaining to greater cell size, and then through congregating into colonial life, and finally by division of labor among the cells themselves. Thus was developed a "body," a greater and better organic workshop and a resistant mass wherein was also stored a greater amount of food, all of which finally led to longevity. By easy stages the single-celled plants (Protophyta) and animals (Protozoa) passed into the more and more complex ones, the many-celled Metaphyta and Metazoa.

The development of living metazoan animals is variably rapid from the fertilized cell into a small community of cells becoming a tiny, hollow, spherical embryo known as the *blastula* (means a little germ, bud or embryo). Such aggregates, developing no higher, are alive to-day (e.g., *Volvox*, a colonial protozoan; these are, however, larger colonies, made up of thousands of cells). The simplest blastulæ show no cell differentiation, and the water-inhabiting invertebrates at this stage of development are usually uniformly ciliated and move freely through the water with a rotary movement about a definite axis, one end of which always points in the direction of movement.

Blastulæ floating about developed into the next stage, known as the *gastrula* (Greek diminutive for stomach), in which the embryo introduces an open cavity for digestion of food. This gastrulation is the result of an inpushing or invagination of the cells of the vegetative or feeding pole of the blastula. The embryo is now a celluliferous two-layered sac, composed of an outer skin, and an inner cavity forming the primitive gut, while its single opening to the exterior is the gastrula's mouth. The animal is now all skin, stomach and mouth (see Pl., p. 155, Fig. 11). In the higher Metazoa the outer layer of cells gives rise to the integument, nervous system, and sense organs of the adult, while from the inner one come the digestive tract and certain of the glands, such as the liver.

All metazoan animals pass through the blastula stage, and the next or gastrula stage as well. This was long ago pointed out by Haeckel and is the basis of his *gastræa theory* of animal development. Then the progressive series of gastrulæ develop body cavities, and because of these primitive pouches are called protocœlomates (means primitive animals with body cavities. See Pl., p. 155, Figs. 29–30). Out of them have come all the higher animals. Most of this life is larval in the living world of the present, and is transitional to higher forms, but in the Archeozoic little of it had progressed beyond the stages of evolution mentioned, and accordingly much of this micro-life floated in the sun-lighted waters of the oceans. Some forms, however, had descended to the sea bottom and glided over or became attached to it. Seaweeds then flourished and probably tiny sponges with nitrogenous skeletons; planulæ, primitive hydroids, and actinians should also have been present; and swimming among the floating life there should have been small jelly-fishes and ctenophores. It was all a soft-bodied life and probably none of the animals attained an inch in diameter.

Collateral Reading

F. D. Adams, Problems of the Canadian Shield: the Archeozoic. In "Problems of American Geology." New Haven (Yale University Press), 1915.

A. P. Coleman and W. A. Parks, Elementary Geology. London and Toronto (Dent), 1922.

CHAPTER XII

THE PROTEROZOIC ERA, OR AGE OF IRON MAKING

The Proterozoic era represents a long time, seemingly 25 per cent of all geologic history. In the Rocky Mountains area at least 37,000 feet of sediments were laid down, and in the Lake Superior region upward of 53,000 feet of strata, and 22,000 feet of volcanics.

Proterozoic Geosynclines. — Schuchert recently plotted most of the known deposits of late Proterozoic time and then had his work confirmed by the leading geologists familiar with these formations. The result is the map, p. 159. From it will be seen that there were in Proterozoic time four seaways: (1) Appalachic, (2) Cordilleric, (3) Ontaric, and (4) Arctic. Of the formations in the Appalachic geosyncline nothing is said in this chapter because they are too greatly altered to make certain their original nature. The deposits of the Ontaric geosyncline are described at greatest length because they are the best known strata of the Proterozoic, while those of the Arctic sea are mentioned under the Animikian. The deposits of the Cordilleric geosyncline are also discussed on later pages. Of these seaways, the only one that is known to have been obliterated through mountain making toward the close of the Proterozoic is the Ontaric geosyncline. This trough is an outgrowth of the previously described Quebec geosyncline (see p. 149).

Were there Proterozoic Epeiric Seas? — The coarse sediments, red oxidized color, and rarity of fossils other than algæ, in Proterozoic formations, along with the abundance of feldspars, have long attracted the attention of geologists, and especially Walcott. After a study of these phenomena he concluded (1916) that the Proterozoic era " was a time of continental elevation and largely terrigenous sedimentation in nonmarine bodies of water. . . . Marine sediments undoubtedly accumulated in the waters along the outer ocean shores of the continent, but they are unknown to us. . . . The known fossils . . . of the Cordilleran geosyncline lived in fresh or brackish waters that were rarely in connection with marine waters," and the algæ reefs of the Newland limestone grew in lakes " several thousand square miles in area."

Since siliceous sponge spicules have been seen in several places, since annelid tubes are also present, and since, further, the algal growths in the Cambrian and Champlainian are always found in connection with marine faunas, it appears more reasonable to assume that all of the recovered Proterozoic fossils are of marine origin. In regard to the fresh-water aspect of many of the formations, it should not be forgotten that the lands then had no vegetation and accordingly no soils. The granites broke down into an arkose which was quickly oxidized,

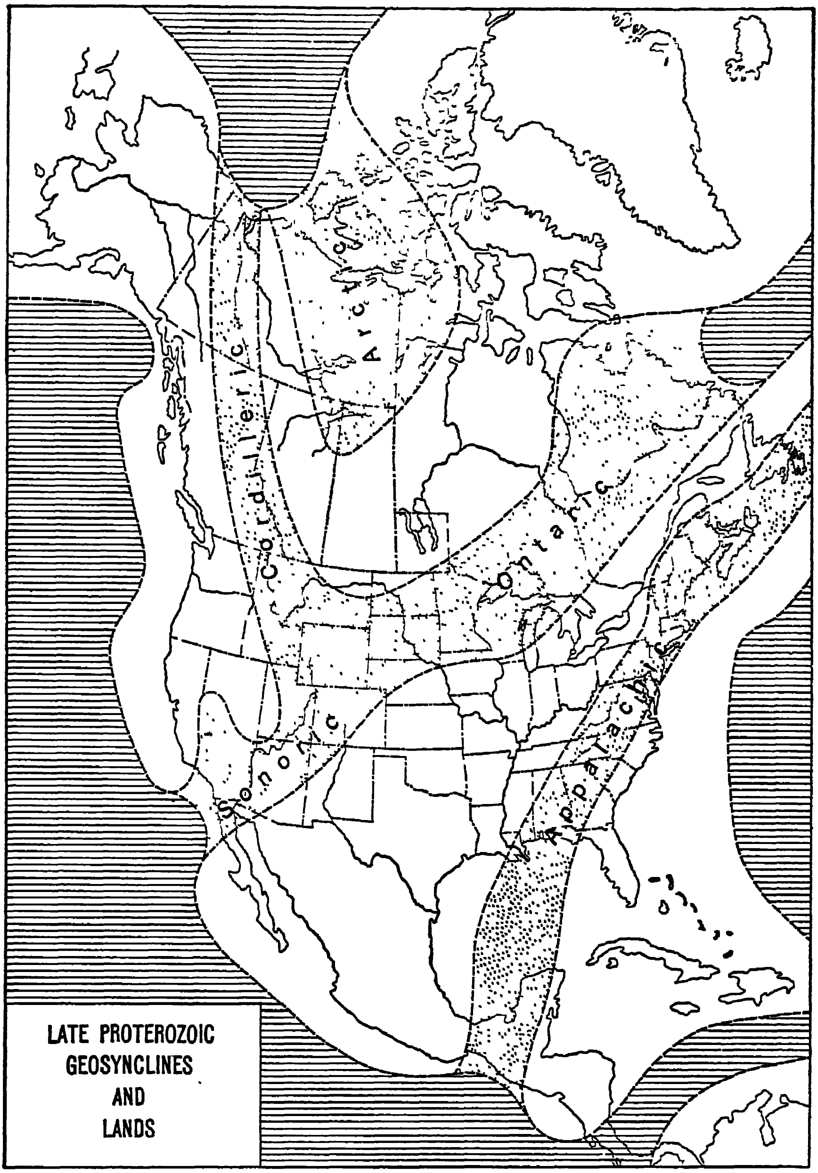

Plate 3. — North America during the later Proterozoic, showing the three geosynclines: (1) Appalachic, (2) Cordilleric, and (3) Ontaric-Sonoric. The fourth seaway (Arctic) appears not to have been a geosyncline, but rather an epeiric sea similar to those of the Paleozoic.

and in this condition were delivered into the shallow-water geosynclines. Therefore the Proterozoic sediments should not always be like those of subsequent times when floras and soils were in existence, and yet those of the Sudburian series and other Proterozoic strata are much like those of the Paleozoic. On the other hand, the animals of the sea could not, or at least were not, obliged to cover themselves with an armor, and therefore as soft bodies they were not preservable as fossils.

North America in Proterozoic Time. — From the geographic position of the earliest Paleozoic seas upon the continent of North America (see Fig., p. 139), and those of the late Proterozoic as well, it is plain that this land mass was not only outlined in much of its present form during the early Proterozoic, but that it was then even larger than it is now. How much larger is not known, but it is established that it was then and for a long time subsequently widely connected by dry land with Greenland and eastward across the sea with Scandinavia. Apparently about 2,000,000 square miles of greater North America has broken down into the oceanic basins in post-Proterozoic time (see Fig., p. 141).

The borderland Appalachis in the east and that of Cascadis in the west also came into existence during the Proterozoic (see Fig., p. 139). At the close of this era the Killarney mountains arose out of the Ontaric geosyncline, dividing the vast interior of North America into a northern (Canadian Shield) and a southern (United States and Mexico) plain. Towards the close of the Cambrian these mountains had in the main been reduced almost to sea-level, so that during the remainder of the Paleozoic, all of the Mesozoic, and most of the Cenozoic, the whole of the interior of the continent was one vast plain. During the Paleozoic this plain was often transgressed more or less widely by epeiric seas, and again late in the Mesozoic. In all of these statements we see that the basin-like form of the North American continent was established early in the Proterozoic, but that the vast medial plain was not a continuity until toward the close of the Champlainian.

Divisions of the Proterozoic. — The Proterozoic rocks may be grouped as follows:

Late Proterozoic time
- Epi-Proterozoic or Lipalian Interval of peneplanation
- Killarney Revolution and mountain making
- Keweenawan volcanic and continental formations
  - Break in record

Middle Proterozoic time
- Animikian-Whitewater sediments with great iron formations
  - Break in record

$\left.\begin{array}{l}\text{Keweenawan volcanic and continental formations}\\ \text{Break in record}\\ \text{Middle Proterozoic time}\\ \text{Animikian-Whitewater sediments with great iron formations}\\ \text{Break in record}\end{array}\right\}$ Beltian series

Huronian series
- Cobalt marine and fresh-water deposits
  - Oldest known tillite and glacial climate
  - Break in record
- Bruce (?Seine) marine series (all or part of the Grenville may be of this time)

Early Proterozoic time
- Ep-Algoman Interval of erosion
- Algoman Revolution and mountain making
- Sudburian (Doréan?) sediments and volcanics

Early Proterozoic Events

Sudburian Series. — Upon the Laurentian peneplain from Lake Huron north to beyond Sudbury, Ontario, there rests a younger series of essentially coarse marine deposits, as a rule conglomerates and sandstones, with from 2 to 13 per cent of shales, all of which are also deformed and metamorphosed, though less so than the Keewatin-Coutchiching and equivalent formations (Fig., p. 162). Carbonaceous material, however, is completely absent in the Sudburian, which is often a cleanly washed sand of fairly equal grain, coming apparently from the north and transported by long rivers to a wide delta built into the Ontaric geosyncline.

The lower part of the Sudburian of Coleman, of variable thickness up to 5000 feet, is heterogeneous in composition. In places there are arkoses (Copper Cliff), the broken-up material of granite, as much as 1000 feet thick, and in others, regularly and cross-bedded thin alternations of grits and muds with angular quartz grains. The arkoses and graywackes full of feldspars are found in close association with the Laurentian granites. These arkoses were probably made under either a desert climate or a cool-moist one, the latter being the more likely. As a rule, the Sudburian has a basal conglomerate, which at Sudbury has a thickness ranging in places up to 5000 feet.

Where the Sudburian is not intruded by the later eruptives, it is but little altered, so that the original bedding, cross-bedding, and even the ripple-marks may still be seen on weathered outcrops. Where intruded by the granites, however, the Sudburian is much metamorphosed. All of the Sudburian is deformed, tilted or sharply bent, with an average dip of 45°, the strata rising toward the granite bathyliths of later intrusion. For this reason, the Sudburian series is sharply marked off from the higher Huronian, which usually lies nearly flat or is but gently folded.

Similarity of Sudburian Formations to those of Later Eras. — As the Sudburian deposits are so very ancient geologically, we note

with Coleman that their apparently modern nature is the most surprising impression made on the observer while in the field. From this we conclude that the atmosphere in character and composition must have resembled that of later times; water did its work then as now, and the extremes of heat and cold seem to have been normal.

Near Lake Timiskaming and at the greatest gold mine of the world, the Hollinger of the Porcupine district, there is a similar series of strata, though there is more conglomerate here. Seemingly of the same general time are the Pontiac series in Quebec, and the Doré conglomerate of the Lake Superior country. The latter is possibly of glacial origin. All of these formations are likewise penetrated by granites of later age. Perhaps most of the sediments are those of shallow seas.

"The Hastings series in eastern Ontario, sometimes considered a less metamorphosed part of the Grenville, is believed by Miller and Knight to be the equivalent of the Timiskaming series, since a conglomerate at its base includes pebbles

Fig. 45. — Sudburian quartzite, crumpled by granitic intrusions, near Cutler, Ontario. Photograph by A. P. Coleman. Yale University Press.

derived from the Grenville. The Hastings series contains limestones, which are infrequent in the Sudbury and Timiskaming series" (Coleman and Parks 1922).

Rocks of Sudburian time are as yet unknown in other parts of North America or elsewhere.

Algoman Granites. — Nearly all of the Sudburian formations are intruded, deformed, and metamorphosed by granites named Algoman by Lawson. They are so much like the Laurentian ones that it is often very difficult to distinguish the two sets of deep-seated intrusives. In fact, the younger ones have been established for only a few localities and all were formerly called Laurentian. Both intrusions made bathylithic mountains.

Middle Proterozoic Time

Huronian Series. — The original "Huronian system" of Logan has undergone much investigation since he studied it in the eighteen-sixties and -seventies, due to the great mining industries more recently developed in Canada. Collins divides the Huronian into a lower Bruce series and an upper Cobalt one.

The *Bruce series* is in the main water-laid, and begins with 1000 to 2000 feet of white conglomeratic quartzite, followed by limestone, graywacke, and more quartzite. The whole of the Bruce series is about 3000 feet thick, and finally the sea withdrew, to be followed by a long interval of land conditions and erosion.

Fig. 46. — Weathered section through a probable sponge (*Atikokania lawsoni*), from the Lower Huronian at Steeprock, Ontario. × 2. Geol. Surv. Canada.

The *Cobalt series* has as its lowest formation a bowlder conglomerate known as the Cobalt *tillite*, which is the oldest known glacial deposit; it will be discussed later in the chapter. This tillite is succeeded by 600 to 800 feet of white quartzite, about 3000 feet of "slate conglomerate," and thousands of feet of red or white quartzite with showy jasper conglomerate. Then come 200 feet of cherty limestone and 400 feet of white quartzite, the whole series measuring probably more than 12,000 feet in the region north of Lake Huron (Coleman and Parks).

In the Rainy Lake area north of Minnesota there occurs in the *Steeprock series* a limestone blue and gray in color and up to 500 feet in thickness, with an abundance of globular masses that may be sponges. These fossils are shown in the figure above.

Animikian or Great Iron Series. — The formations of Animikian time have a wide distribution over the Canadian Shield, the Ontaric and Arctic seas, it is thought, having transgressed far and wide over the older rocks. Most of the deposits are of marine origin, though some appear to be of a continental character. However, the Animikian formations are not now of universal distribution over the shield. On the contrary, the areas are widely isolated and appear in the main to be remnants preserved from erosion in the down-folded or gently down-warped basins in the older rocks.

The Animikian strata generally lie nearly horizontal and are very little metamorphosed, but in other areas are folded into large pitching anticlines and synclines. In the Penokee area of Michigan the formations that remain after their long exposure to the erosive forces are still 14,000 feet thick, but elsewhere they are usually reduced to a maximum of about 6000 feet.

The very thick *carbonaceous deposits* of the Animikian clearly mark the effective beginning of oxygen in the atmosphere, and the red color of much of the Keweenawan and some of the Animikian sediments may indicate an increase in free oxygen to the point where it became effective as an enormous stimulant to the spread and rapid evolution of the animal kingdom.

The deposits of the Animikian may begin with a basal conglomerate of pebbles of the Keewatin schist and Laurentian gneiss. This passes into chert or jasper that may be banded or oölitic, or into beds of impure limestone or dolomite with chert. Higher in the series there are great thicknesses of thinly laminated carbonaceous slate with large concretions of marcasite, and it has been calculated that if all of the carbon in these argillites (6 to 10 per cent) were concentrated, it would make a bed of anthracite 200 feet thick. There is also much sandstone. Near Port Arthur the Animikian is intruded by sills and dikes of diabase or trap of Keweenawan age, the sills varying from an inch up to 200 feet or more in thickness, and near Sudbury there are interbedded tuffs with a depth of 3800 feet. On the north of Lake Huron (Thessalon) the Animikian strata appear to be of continental origin.

"The wide-spread shallow seas of the Animikie," says Coleman, "had one feature scarcely repeated on the same scale in later times, the deposition of iron compounds with associated silica. In nearly all of the Animikie areas there is an 'iron formation' [in places as much as 1000 feet thick], with cherty ferruginous carbonate or oölitic greenalite or jasper. . . as the initial stage, from which are formed by secondary causes small or large bodies of ore, culminating in the immense and rich deposits of the Mesabi to the southwest of the shield in Minnesota." Other great fields occur in the Penokee-Gogebic region of Wisconsin and Michigan,

and in the Menominee area, which lies chiefly in the latter state.

The iron-ore mined in the United States in 1916 was about 75,000,000 tons. At the mines this ore was worth on the average about $2.34 per ton. The Lake Superior district furnished nearly 85 per cent of the iron mined in the United States and about 8 per cent came from Birmingham, Alabama. The Adirondack region is third in quantity of iron mined.

Lake Superior Iron Mines. — The hematite ores found along the south and west sides of Lake Superior in the Archeozoic and Proterozoic formations are in the main (70 per cent) from the Animikian series. Most of the richest ores occur near the surface and for 1000 feet downward. Originally the iron formation had a content of about 25 per cent of metallic iron, but in places it has been concentrated and in these, which form the mining areas, the amount in the ores now mined is about 59 per cent. The Marquette, Michigan, field was opened in 1849, and that of the Mesabi in 1892. In 1920 Minnesota produced 40,000,000 long tons and Michigan about 19,000,000, making up about 85 per cent of all the iron-ores mined in that year in the United States. On account of the enormous scale upon which these rich mines are now worked they will become exhausted during the present generation. Vast bodies of lower grade ores remain, however, which will gradually come into economic use, but their lower content of metal will mean, in so far as that factor is concerned, a higher price of iron. The rich ores utilized in the present generation have been no small factor in the present great industrial expansion of the United States and Canada.

In the southern portion of Hudson Bay, E. S. Moore (1918) has described in detail the iron-bearing series of the Belcher Islands, which is nearly 10,000 feet thick. The formations consist of sandstones (42 per cent), limestones and dolomites (34 per cent), banded slates (14 per cent), iron strata (5 per cent), and diabase-basalt (5 per cent). One of the more interesting features is a thick (428 feet) zone of concretionary limestone, the deposits of *blue-green algæ*. These spherical and subspherical masses range in size up to 15 inches across and suggest similar Proterozoic fossils described as *Newlandia* and *Collenia* (Figs., pp. 176, 177). Much oölite is also associated, and apparently some of the microscopic *single-celled algæ* are preserved. Moore suggests "that the algæ and iron bacteria have been responsible for the precipitation of colloidal silica, hematite, and iron silicate in this granular form, in some places as a direct precipitate [in thin bands] on the floor of the basin and in others as a replacement of the calcite granules by the iron compounds."

Llano Series of Texas. — In central Texas, the earth's crust is domed, bringing to the surface through profound erosion an ancient series of formations. These are some thousands of feet thick, consisting of alternations of shale, sandy shale, sandstone, limestone, and schists. They strike east and west and the general dip is to the south. In places these strata are but little metamorphosed and in others changed into schists, marbles, and gneisses, due in the main to two series of granitic bathyliths. These intrusions were of great extent.

After the deposition of the Llano strata and the granitic intrusions, the entire central area of Texas was folded into mountains that had an east and west strike. Then followed a long time of erosion and complete peneplanation before

the sea of Upper Cambrian time crossed the roots of these mountains. This movement has been called the *Llano orogeny*, but the whole extent of the mountains is not yet known.

The Llano series is believed to be of about the same age as the Grand Canyon series of Arizona (see p. 167).

Late Proterozoic of the Cordilleras

Beltian Series. — The best known and thickest sections of Proterozoic formations in western North America occur in western

Fig. 47. — Limestones and cherts of the Proterozoic (Castle Mt. group), Flathead County, Montana. Photograph by Walcott, U. S. Geol. Surv.

Montana, eastern Idaho, and British Columbia, north to at least 54° north latitude (see Fig., above). Upward of 37,000 feet of sediments, mainly sandstones and shales, are exposed in the combined sections. In the Cabinet Range, Montana, the thickness is about 35,000 feet (Calkins). A striking feature of these Beltian formations of the Cordilleras, Lindgren states, is the small amount of igneous materials. Diabase intrusions of small areal extent are known, and it is probable that there are also some basalt flows. North of the International Boundary, however, extensive intruded sheets are referred to the Proterozoic.

The Cambrian overlies the Proterozoic strata in Montana and British Columbia with apparent conformity, and yet there may have been as much as 16,000 feet locally removed through erosion preceding the overlap mentioned (see Fig., below). In the lower part of these sections occur three great limestones, pure and impure, that have thicknesses ranging between 2000 and 4800 feet. It is in these calcareous zones that lime-secreting algæ abound. The bulk of the sediment, however, is sandstone, and it is significant that above the basal portion much of it is red in color, ripple-marked, and sun-cracked. As the clastic portion

Fig. 48. — Disconformable contact of the Lower Cambrian quartzite on the Beltian shales (Hector formation). In the Rocky Mountains this contact is never an angular one, the difference of dips rarely being as great as 10°. Geol. Surv. Canada.

thickens to the west at the expense of the limestone, we see that it is from this direction that the sediment was mostly derived. The inference seems to be that the earlier sediments are of marine origin, while the later formations are either delta deposits or are continental and of a semiarid climate.

In the *Grand Canyon*, Arizona, occur the Chuar and Unkar formations with a thickness, remaining after an unknown amount of erosion, of nearly 12,000 feet, most of which is sandstone, while

of limestone there is only 435 feet, and that near the base. The sediments are at first of marine origin, but quickly pass upward into continental deposits (see figure below). These formations rest on the peneplained surface of the highly deformed Archeozoic (Vishnu) strata.

Grand Canyon Revolution. — After the deposition of the Grand Canyon series, and long before the Paleozoic, the strata were broken into many blocks, let down through faulting into the Archeozoic masses, and later on both were raised into a mountain system similar

Fig. 49. — View east up Colorado River, near mouth of Bass Canyon, Arizona. On the left and above are horizontal Paleozoic strata resting on peneplained monoclinal beds of the Proterozoic (Unkar). The latter lie upon the tilted and peneplained Archeozoic (out of view) in the Granite Gorge of the river. Photograph by L. F. Noble. Also see Frontispiece.

in aspect to the present Great Basin ranges. This orogeny may be known as the Grand Canyon Revolution. All were eroded to sea-level before the Paleozoic era began, for the horizontal Cambrian strata rest upon the peneplained older formations. In other words, after the deposition of these Proterozoic sediments, the rocks of the Colorado plateau region were profoundly block-faulted, tilted eastward, and elevated into a monoclinal attitude, and the resulting mountains were presumably high. How long it took to reduce this highland to sea-level is unknown, but the eroded peneplain is indicated by a marked unconformity.

Late Proterozoic of Lake Superior

Lower Keweenawan. — The Keweenawan division of rocks was introduced by T. B. Brooks in 1876, and includes the youngest of Proterozoic strata. They are all of continental origin, and of quick accumulation. Geologists are agreed that there is a distinct break in the record between the Animikian and the Keweenawan series of formations. Moreover, the sediments of the former are of marine origin, while those of the latter are held to be of continental deposition. Some geologists hold that the Keweenawan should be referred to the Paleozoic, but the trend of opinion since Walcott's discussion of it is that it should be regarded as the closing period of the Proterozoic era, a belief that is followed in this book. The Keweenawan is characterized by enormously thick deposits, both of sediments and lavas, the igneous activity becoming greater in its middle and upper portions.

At the base, from Wisconsin eastward, there are conglomerates, well stratified, coarse, red and white sandstones interbedded with conglomerates, thin impure limestones of various colors, and shaly rocks, the whole having a thickness of from 300 to 1400 feet. These are also penetrated by dikes and sills of diabase or trap of Upper Keweenawan time. The sediments are largely derived from the Laurentian granites, but red jasper pebbles of the iron formations also occur. Ripple-marks are common, the sandstones are often feldspathic and might be called arkose, and the shales have mud-cracks, all of which are indicative of continental origin. Further, the prevailing color is red, like the Triassic of the Connecticut valley, suggesting semiarid conditions and complete oxidation; the absence of carbonaceous beds is also strikingly different from the conditions found in the Animikian sediments.

Upper Keweenawan Volcanics. — The closing period of the Proterozoic record is marked in the region of Lake Superior and elsewhere by a tremendous outpouring of volcanic materials upon the dry land, probably not by volcanoes but rather through fissures. Most of the formation, according to Coleman, "consists of basic lava flows, variously called trap or diabase or melaphyre, some being really basalts, but there are also more acid [feldspathic] flows, referred to as porphyries and felsites, really rhyolites. In subordinate amounts ash rocks and lapilli are found between the lava sheets, and the [interbedded] conglomerates and sandstones [and shales of small amounts] are made of almost contemporary material, especially of fragments of the rhyolites and porphyries."

One of the thickest series of lavas known on the Canadian side of Lake Superior occurs on Michipicoten Island where a section was measured with a thickness of 11,230 feet, only a small part of which consists of sediments. In northern Wisconsin and Michigan, Van Hise and Leith give the maximum thickness of their Middle Keweenawan (after allowing for initial dip during accumulation) as upward of 30,000 feet. Of this, from five eighths to eight ninths is igneous material, the rest being red conglomerates and red sandstones derived from the volcanics.

Over the "Middle Keweenawan" of Wisconsin and Michigan lies the local "Upper Keweenawan," made up of conglomerates (800 to 4000 feet), sandstones (15,000 feet), and shales (100 to 400 feet), attaining a total thickness of about 20,000 feet. All of this material is, however, detritus from the igneous Keweenawan, and does not signify a long interval of erosion, because of the soft nature of the volcanics and the high and rough topography of the lava field.

The volume of known igneous material extruded (estimated as 24,000 cubic miles) was accumulated in a sinking field, and in this way arose the *Lake Superior geosynclinal basin*, which is almost devoid of subordinate folds. In other words, the molten material as it rose to the surface permitted the upper formation to sink in. Elsewhere, however, the Keweenawan rocks still lie almost horizontal, and in general their appearance is not unlike similar Paleozoic formations, though block faulting is common.

Upper Keweenawan Metals. — From the human and economic point of view, the advent of the Keweenawan lavas was one of the most important events in the pre-Cambrian history of the Canadian Shield, since most of the valuable ore deposits of the region, so far as known, are connected with the igneous activity of this age. At Thunder Bay the *silver ores* of Silver Islet and other mines were supplied by the Keweenawan diabase dikes and sills, Ontario in 1913 yielding over $36,000,000 worth of silver. The unrivalled mines of *native copper* in Michigan belong to the amygdaloids and conglomerates of Keweenaw Peninsula, and similar ores of native copper, perhaps on a larger scale, exist in the extensive area of amygdaloids east of Great Bear Lake and near Coppermine River in the extreme north of the shield.

The native "low grade" copper ore of Michigan was discovered by Douglas Houghton in 1830, though worked long before by the Indians. The area in which it occurs is 70 miles long by 3 to 6 miles wide. The famous Calumet and Hecla mines were opened in 1846, and in the following year Michigan produced 239 tons of copper. In 1916, when it reached its maximum output, the yield was

135,000 tons, valued at $66,300,000. The total output to the end of 1922 was 3,500,000 tons of copper, and has been exceeded only by that of Butte, Montana.

"The Sudbury [Ontario] deposits of *nickel and copper*, including much the largest mines of nickel in the world, are connected with a sheet of norite-micropegmatite probably of Keweenawan age; and Miller has concluded that the singularly rich silver veins of Cobalt have derived their ore from a great diabase sill which ascended into the Cobalt conglomerate at this time.

"The Keweenawan eruptives seem to have brought with them copper, nickel, and silver in large amounts, cobalt, gold, platinum, and palladium in much smaller amounts; and if the iron mines are left out of account, almost all the metalliferous deposits of the southern margin of the Canadian Shield have resulted from the coming of its dikes or sheets or lava streams." (Coleman.)

Gold and silver, Lindgren states, are obtained in the eastern part of North and South America mainly from the rocks of Archeozoic and Proterozoic age. Almost all primary gold and silver vein deposits have been formed during or shortly after epochs of volcanic or intrusive activity. Gold is the principal metal and is always accompanied by quartz gangue.

Killarney Revolution. — Collins (1922) has shown that the whole area of the Ontaric geosyncline from at least Sudbury, Ontario, into southern Wisconsin, was folded and injected by granite bathyliths, making the Killarney mountains. These have long been known as the "Lost mountains of Wisconsin," and Lawrence Martin thinks they may originally have been as high as the present Alps. In a northeast direction the Killarney mountains are known to have extended at least 1000 miles, from southwestern Minnesota (Sioux Falls) to beyond Lake Huron (see map, p. 193).

Climates of Proterozoic Time

Tillites of the Huronian. — One of the most surprising of recent discoveries in Geology was the finding by Coleman of tillites (morainal deposits of glacial till or bowlder clay, hardened into stone, see Pt. I, p. 144, and Pt. II, Figs., p. 173) in the Huronian formations of Canada, and the consequent establishing of the occurrence of a *glacial climate* thus early in the history of the earth. Over the wide Laurentian peneplain previously described, there is found in the country to the north of Lake Huron a basal conglomerate that often includes facetted and striated bowlders of various kinds of rocks. Over the tillites occur, locally, thick zones of banded (varved) slate

and water-formed conglomerates and quartzites. (See map below for distribution.)

The whole thickness of glacial beds is usually not more than 500 or 600 feet, somewhat in excess of the thickness of the recent Pleistocene glacial and interglacial beds at Toronto. This Huronian tillite is known to cover an area of 1000 miles from west to east and 200 miles north and south, down to 46° north latitude, and rests upon a nearly plane surface that still lies not far above sea-level. It is the material of a continental ice sheet which deposited its content of rocks and earth upon the land.

"Bowlders of granite and greenstone with diameters up to 2 or 3 feet are common and larger ones measuring 5 feet through are occasionally met. . . . These bowlders may be well rounded, subangular, or angular. They may be crowded

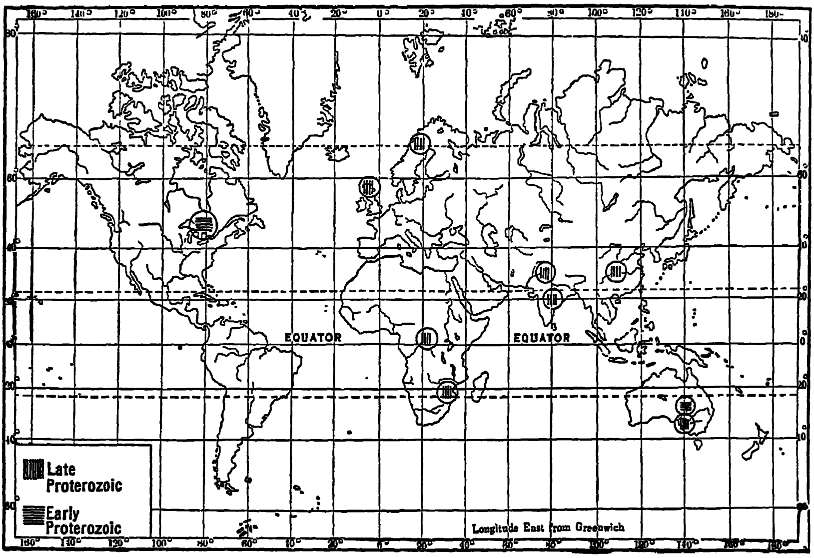

Fig. 50. — Areas of early and late Proterozoic glaciations.

into a mass of large and small stones cemented together, or they may lie sparsely scattered in a fine-grained matrix, the red granites showing up sharply from square yards of dull greenish gray ground mass. Generally no marked stratification can be seen in the coarser conglomerates, though associated pebble conglomerates and slates may be well stratified. . . . The matrix and the bowlders enclosed vary greatly from point to point, roughly corresponding to the character of the rocks beneath, and the rock strongly suggests a glacial moraine in some cases and bowlder clay in others." (Coleman.)

At the top of the Proterozoic series in the Wasatch Mountains, Utah, Hintze and Calkins (1920) report a tillite, bluish green in color, fine in grain, with scattering pebbles up to 6 inches across, some of which are facetted, and bowlders up to tons of weight,

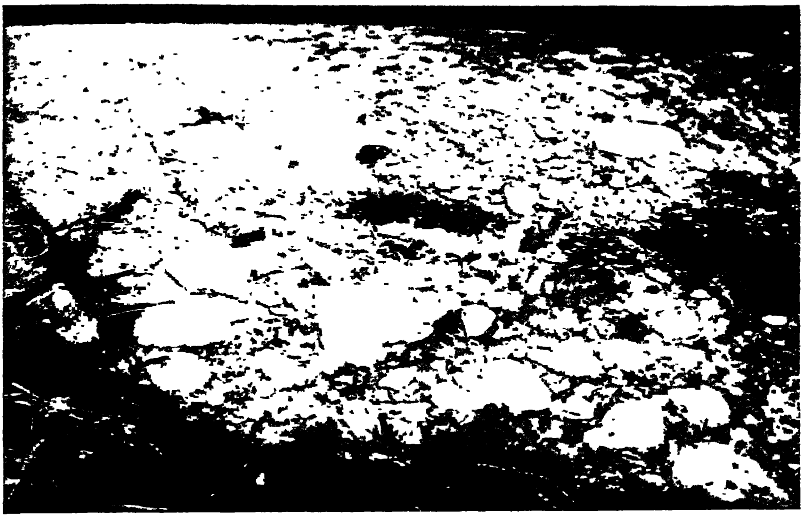

Fig. 51. — Eroded exposure of the Huronian tillite, near Cobalt, Ontario. Photograph by A. P. Coleman. Yale University Press.

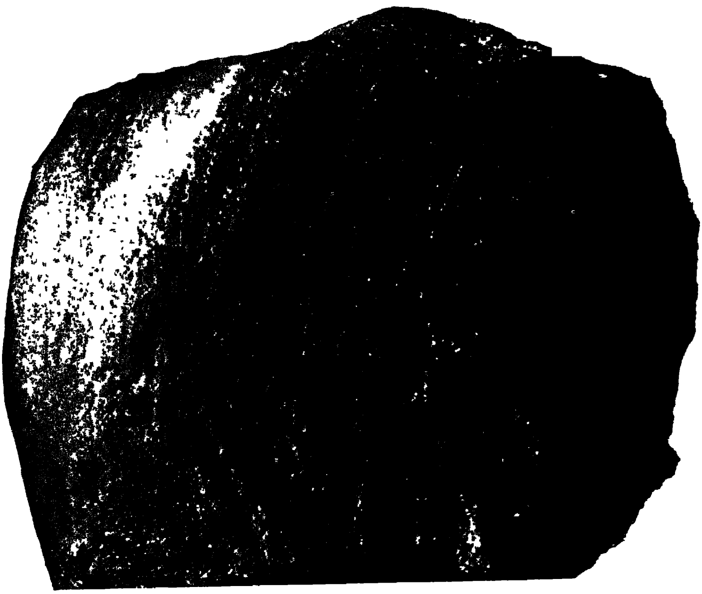

Fig. 52. — Striated bowlder of the Huronian tillite, Cobalt, Ontario. Photograph by A. P. Coleman. Yale University Press.

of quartzite, limestone, and granite. Apparently no striated stones have been seen.

Other Proterozoic Tillites. — Undoubted and probable tillites of Proterozoic age are now known in many lands: certainly in Norway, China, India, and Australia, and probably in Africa. They are of different ages, some occurring at the close of the Proterozoic and others older (see Fig., p. 172).

It has often been stated that the Cambrian began with a glacial climate, but in all places where tillites are known in connection with strata of this age, it has not yet been demonstrated that such are actually a part of the Cambrian. In some places, the tillites disconformably underlie fossiliferous Cambrian strata, and in others no strata with fossils occur with them. It is therefore not yet established that any of these tillites are of Cambrian time, and we prefer to hold that they are for the present better referred to the Proterozoic. These are the tillites of Australia, Norway, and China.

A series of unmistakable tillites followed by seasonally banded slates occurs in *southern Australia,* having a thickness, according to Howchin, of between 600 and 1500 feet. These lie just below fossiliferous Lower Cambrian strata, and the tillites are also referred to this period. Below the tillites, the section continues unbroken for tens of thousands of feet, and all are devoid of fossils. Since the section goes unbroken downward, and since the tillites have not been shown to continue into the Lower Cambrian, we hold that it is best to refer the tillites and all the coarse strata beneath them to the Proterozoic. Andrews has recently shown (1922) that at least those of the Broken Hill area are of *early* Proterozoic age.

Other tillites of *northern Norway* were made known by Reusch as long ago as 1891, and have recently been restudied by Holtedahl (1922). They occur below the Lower Cambrian sandstones having the Holmia fauna, and terminate the Sparagmite (feldspar-bearing) sandstones. The latter attain in places a thickness up to 6500 feet, and are often compared with the *Torridonian sandstones of Scotland.* The latter series occurs at the top of the Proterozoic and is also thought to have tillites, or is the material of a subtropical desert having icy storms. Below the Norwegian sparagmites occur the Trysil or Dala sandstones referred to the Proterozoic. Under date of April 21, 1921, Holtedahl writes: "It is now proved that warping movements took place during and after the time of the tillite deposition and before Holmia time. The Norwegians think the tillites and the Sparagmites are of Lower Cambrian age and transitional to them." This may be so, but until it is proved we prefer to think of them as late Proterozoic in age. The tillite is made up of bowlders, often of large size, of granite, diabase, gneiss, quartzite, sandstone, and limestone. As yet, no glacial striæ have been found. The unmistakable tillites of *arctic Norway,* formerly referred either to the Cambrian or the Proterozoic, Holtedahl has recently shown to be of Champlainian or Silurian age.

Still other Proterozoic tillites are known in *peninsular India.* They also occur in the *Himalayas* in the upper part of the thick Vindhyan system. In the Simla area, also of the Himalayan region, is another thick series of Proterozoic

strata, and in the lower division, the Blaini series, occurs a bowlder bed with rounded and angular stones, some of them facetted and striated by ice action, bound together by a fine-grained slate. The bowlders suggest an origin in floating ice or from melting icebergs that drop them upon the mud-gathering bottoms. Overlying the bowlder bed occurs a thick mass of carbonaceous slates, the Infra-Krol series (Wadia 1919). H. H. Hayden compares the Blaini bowlder bed with the tillites of the Talchir (Permian).

In *China*, in the provinces of the middle Yangtse River, Willis and Blackwelder have discovered unmistakable tillites the exact age of which has not yet been established.

Another occurrence of tillites is in the Griqua Town series of *South Africa*. Here in the Hay district are found "striated and flattened pebbles and bowlders." These are accepted by Rogers as glacially striated. According to Du Toit, tillites of the same age (Proterozoic) occur in Namaqualand and in the Transvaal. Other tillites, but apparently of a different Proterozoic time, occur in the Congo country.

Conclusions on Pre-Cambrian Climate. — The very thick limestone series of both the Archeozoic and Proterozoic suggest that at the time of their formation the climate was at least mild. Then, too, the many zones of algal concretions, some of which are actual reef-limestones, point also to warm waters. In the Proterozoic, the vast amount of iron deposited also is confirmation of mild climates. We may, therefore, conclude that at this very early time in the history of the earth the geologic climates were in general of the same nature as they have been ever since. In other words, the evidence indicates that during long stretches of time the temperature of air and water was mild and fairly uniform the world over, but that at somewhat irregular intervals cold climates developed that were geologically of short duration. The times of reduced temperatures appear to coincide with the beginning or close of the eras and periods, when the lands are largest and highest.

Life of the Proterozoic

It is not so long since it was thought that the Proterozoic strata were devoid of recognizable fossils, but during the past twenty-five years Walcott has described such from various places and Cayeux has secured Radiolaria (Fig., p. 70), spicules of the four orders of siliceous sponges, and possibly Foraminifera (Fig., p. 68), from Brittany in France. Near the top of the Grand Canyon series, Walcott has also found in limestones (Chuar) an abundance of siliceous sponge spicules. A careful search among the Proterozoic flints would probably reveal more of these, and one through the limestones might yield undoubted Foraminifera and possibly other micro-organisms.

The most abundant fossils of the Proterozoic limestones are the secretions of *calcareous algæ* commonly known as *Cryptozoön* (Figs., pp. 176–177). These coral-like plant masses make entire beds that repeat themselves time and again through thousands of feet of limestone. Moore (see p. 165) has described great quantities of these algæ as common to the iron strata of Hudson Bay, and Grout and Twenhofel have done the same for the similar strata of Minnesota and Michigan.

Fig. 53. — Single head of an alga (*Newlandia concentrica*), from the Beltian series, Montana. × ⅔. After Walcott.

Walcott has shown that certain of the Proterozoic (Beltian) limestone formations abound in a variety of layered secretions due to the physiological processes of algæ (blue-green). He describes them under six new genera and ten species. Most of them occur in abundance in the Newland limestone in Montana throughout a thickness of 2000 feet. Higher up come the Greyson shales, 3000 feet thick, with marine annelids, but without the algæ. Still higher are the Spokane shales, 1500 feet thick, and here again in a thick zone the algæ abound. We may, therefore, truthfully say that the Proterozoic strata abound in fossils, but not in such forms as would be expected from the evidence of the Paleozoic formations. It is rather a plant world of the lowest type, that has left inorganic structures from which but little of the original organisms that caused their formation can now be learned.

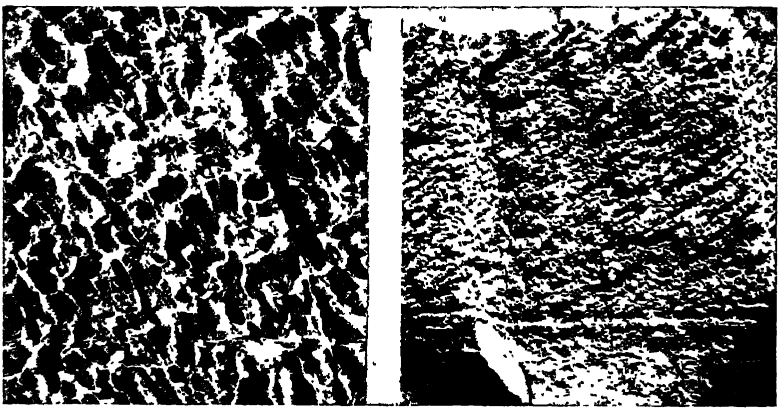

Fig. 54. — Internal structure of a Proterozoic alga (*Camasia spongiosa*), from the Beltian series, Montana. About natural size. After Walcott.

From the upper portion of the Proterozoic (Beltian series) of Montana, Walcott has described a number of *worm tubes and trails*, seemingly of segmented annelids, that were found 7700 feet beneath the top of the section (Fig., p. 178). They are among the youngest fossils known in the Proterozoic, and even though they are only tubes and trails they seem to indicate the presence here of free (errant) annelids, a class of marine invertebrates high in the line of organic evolution. It is also interesting to note here that Walcott has discovered in Montana *Micrococcus*, one of the "immortal types," a form related to *Nitrosococcus* living to-day. There are still other

Fig. 55. — Proterozoic reef of calcareous algæ (*Collenia ? frequens*), Flathead County, Montana. Photograph by Willis, U. S. Geol. Surv.

fossils, but their nature is too obscure to make out their relationship to known organisms.

This evidence shows that life was present in abundance early in the Proterozoic, and that it consisted mainly of marine algæ. In the later Proterozoic occur Protozoa (Radiolaria), Annelida, and various types of siliceous sponge spicules, and from the nature of the Cambrian faunas we must infer that trilobites were also present. This means that most of the invertebrate classes of organisms were in existence in Proterozoic time.

The apparent *absence of lime-secreting animals* in the Proterozoic has been explained by Daly and Lane as possibly due to a lack in available form of lime salts in the oceans and seas of this early era. In other words, it is held that

even though vast limestones were formed, there was no lime available for organic skeletons and hence there could be no structures that were preservable as fossils. Daly has suggested that the small amount of lime then being delivered by the rivers to the seas was quickly precipitated through the continuous decay of organisms, since there were no bottom-feeding or scavenging animals to eat the dead organic matter. The massive deposits of calcareous algæ of the Proterozoic are not skeletons but the involuntary secretions due to the metabolic processes of these plants. That the marine waters of this ancient time may have

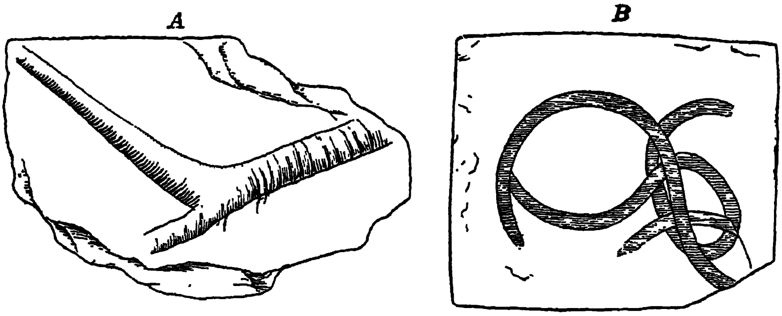

Fig. 56. — Proterozoic worms. *A*, cast of large burrow (*Planolites corrugatus*). *B*, imprint of the actual annelid tube (*Helminthoidichnites meeki*). After Walcott.

had a different salt content, and one devoid of the cyclic rotation of organic matter from animal to animal, as held by Daly and Lane, and that this difference led to different physiological processes among the organisms, preventing the invertebrates from using lime in their skeletal parts, appears more probably true.

Collateral Reading

R. S. Daly, The Limeless Ocean of Pre-Cambrian Time. American Journal of Science, 4th series, Vol. 23, 1907, pp. 93–115.

CHAPTER XIII

THE LIPALIAN INTERVAL

Following the known events of the Proterozoic era, and before the introduction of Paleozoic strata with their abundance of fossils, there is a vast blank, a break of very great significance. During the time of this Epi-Proterozoic interval, which Walcott has called Lipalian time (from a word meaning gone or missing), the continents appear to have stood well above the general oceanic level, and the chief geologic work done was that of erosion. Of course a record was being made somewhere in accumulating strata, but these deposits are as yet wholly unknown. For this reason, wherever Paleozoic or later formations lie upon the Proterozoic, there occurs a most significant break between them. This break, represented by an unconformity of the first order, must be fully understood, and a description of it will also make more clear all other intervals and breaks.

It is now the custom of geologists to speak of the unconformities also as breaks and intervals: *breaks* for the shorter times of lost record represented by the disconformities and diastemata, and *intervals* for the greater ones seen in the angular unconformities.

Erosion intervals and unconformities are of very variable duration in the different areas of the lands. They may be so short that geologists have the greatest difficulties in discerning the breaks, and on the other hand they may appear as if embracing nearly all of geologic time. It is of common occurrence on the Canadian Shield to find the Archeozoic formations overlain by the almost recent Pleistocene glacial deposits, and even these may be absent. It then appears as if in such places no rocks had been deposited, either by the sea or by the forces of the land, since Archeozoic time, and yet geologists know that the shield has been variously covered by sheets of sediments formed at sundry times in the Proterozoic, Paleozoic, and, to a more limited extent, in the Mesozoic.

We have seen that some geologists refer the Keweenawan to the Paleozoic, but most workers hold that the formation of this series was the latest event in the Proterozoic, and that a long interval occurs between this series and the oldest deposits of the Cambrian. Further, in most places on the shield the Keweenawan was never

laid down, and the Animikian and even the Huronian may have been eroded away before the seas of Cambrian time again invaded the area. Therefore, the pre-Cambrian interval is locally very variable in its apparent duration, but from the standpoint of the ascertained geologic record in its most complete form, it does not seem that this break can be more important than the similar ones between the other eras. Accordingly, we may say that the interval appears to have lasted very long, but as there are so few late Proterozoic fossils at hand, and therefore no record of organic evolution to guide us, the length of the interval cannot as yet be determined.

Where the Paleozoic strata rest on the Proterozoic, there is in most places a marked and usually an angular unconformity. In western Montana, Idaho, and British Columbia, however, the Paleozoic rests without a marked unconformity on the earlier formations of the Proterozoic or Beltian series (see Fig., p. 167). This condition means that here the lithosphere was not folded toward the close of the Proterozoic, and in fact not until the close of the Mesozoic.

The marked and usually angular unconformity beneath the base of the Paleozoic means that more or less thick sheets of rock or even mountain ranges had been elevated and subsequently worn away. Therefore the land areas of Lipalian time were reduced to a low-lying plain, a peneplain, and all this before Paleozoic time. It was over these eroded and flat lands that the Paleozoic seas spread their conglomerates, sands, muds, and limestones with their fullness of fossils. We learn therefore during Lipalian time only of the destructive work of the aerial forces, a work of slow action through the agencies of the atmosphere, oxygen, carbonic acid, water, temperature, wind, and gravity. Grain by grain the high places of the lands were transported into the seas and oceans (study Frontispiece, and Fig., p. 168). How much time was consumed, no one knows, but it was long enough for much of the animal world to change its soft skin to one protected by an inflexible covering of carbonate of lime such as is seen in the corals, cystids, brachiopods, and gastropods of the Cambrian.

Walcott speaks of Lipalian time as the "era of unknown *marine* sedimentation between the adjustment of pelagic life to littoral conditions and the appearance of the Lower Cambrian fauna." In other words, the term Lipalian stands for the unrecovered Epi-Proterozoic interval, a time consumed by the marine animals in evolving from floating and swimming forms without exterior

skeletons to the manifold life of the Cambrian with its protective coverings.

Lipalian Oceans. — The North American continent throughout Lipalian time is thought to have stood well above the average of oceanic level during this time. What is true of North America appears to be equally so for all the continents, since nowhere are there any known Lipalian marine formations. These facts suggest that toward the close of the Proterozoic the earth's lithosphere underwent one of its greatest readjustments, seemingly the greatest of its several "critical periods" known to geologists. Accordingly, the ocean basins were then overdeepened, greatly lowering the oceanic level and causing the continents to appear as having been much raised above it. For these reasons it is thought that all of the Lipalian marine deposits were laid down at lower levels than those of subsequent times and hence are forever buried in the oceans.

The low strand-line of Lipalian time has subsequently come to hold a higher level, in consequence partly of the wear and tear of the continents carried into the oceans, but probably mostly because of the vast quantities of new waters added through volcanic activity from the interior rock magmas. It is thought that the amount of water so added since Lipalian time may equal 10 per cent of the present oceanic volume.

During Lipalian time, when all the continents stood well above the strand-line, erosion was very active, and through the wearing down of the lands much new salt was freed from the rocks and added to the oceanic waters. This increase in salinity may have been an added stimulus toward forming the outer shells or skeletons in the invertebrate animals, and combined with another cause — a more profuse adaptation to the bottoms of the shallow seas, leading to crowding and a fiercer struggle for existence — brought on quickened evolution and the necessity for external armoring; hence a skeleton either of chitin with some lime or one wholly of carbonate of lime. Siliceous skeletons had long before been adopted by the radiolarians and sponges.

Collateral Reading

C. D. Walcott, Abrupt Appearance of the Cambrian Fauna on the North American Continent. Smithsonian Miscellaneous Collections, Vol. 57, 1910, pp. 1–16.

CHAPTER XIV

THE PALEOZOIC ERA

We have so far studied in a most general way the more important geologic events of the earlier half of the earth's history. Now we begin to take up in more detail the remaining chronology, and first the historical geology of the Paleozoic era. The position of this chapter in the volume shows at once that the greater part of the earth's known history is subsequent to the pre-Cambrian, and this far more exact knowledge is due not only to the better preserved rock record, but especially to the abundance of fossils. The strata of the later half of the earth's history are also usually far less altered and deformed by internal forces. The older formations, on the other hand, even if they had not been so much metamorphosed, would still lack fossils in abundance, for the reason that during the hundreds of millions of years which they represent the organisms were devoid of preservable parts.

Definition of Paleozoic. — Upon the vastly thick masses of ancient igneous, sedimentary, and metamorphic rocks of Archeozoic and Proterozoic times, rest in usually marked unconformity the abundantly fossiliferous strata of the Paleozoic era. In the past century, geologists in general held that these rocks contained the evidences of the *first life* that appeared on the earth. Accordingly, Sedgwick in 1838 named the lower part the *Paleozoic series*, the name meaning *ancient life*, as he then believed it to contain the first life. Since then, however, as previously shown, fossils have been found in the Proterozoic, and it is now held that low forms of life lived also in the Archeozoic. Nevertheless, the term Paleozoic is not only retained for the part defined by Sedgwick, but has been extended until it is now understood to embrace all of the time and rocks between the older Proterozoic era and the younger Mesozoic era. The Paleozoic is at present regarded as the third geologic era in the history of the earth, or the third volume of the "book of geologic time."

Paleozoic of North America. — North America is wonderfully rich in a long succession of Paleozoic formations that abound in fossils, and this is especially true for the eastern half of the United States and Canada. No other continent is so rich in this history.

In addition, the Paleozoic strata of Europe are as a rule much disturbed and metamorphosed, making them very difficult to interpret, while in North America, over vast areas west of the Appalachian Mountains, the highly fossiliferous strata lie almost as they were deposited, although of course much consolidated by time. When these strata weather away, they yield their entombed organisms freely, and innumerable kinds of fossils are to be had by those who will look for them throughout the great valley of the Mississippi

Fig. 57. — Limestone exposure at Newsom, Tennessee. At the top are black shales of the Mississippian, resting disconformably on six feet of Middle Devonian, which in turn lies disconformably on the Middle Silurian.

River and in southern and medial Canada to beyond the Arctic Circle.

With the beginning of Paleozoic time, this abundance of fossils furnishes a ready and reliable means of correlating the formations not only from place to place but even between continents. Hence we have in most post-Proterozoic strata a far more detailed classification of the events, and also a greater knowledge of two parallel evolutions, that of the rocks and that of the organisms. As these two sets of phenomena are constantly interacting, they are checks

upon each other in the determination of the actual events which happened at any time at a given place. In other words, because of the abundance of fossils in the Paleozoic and subsequent times, we have a ready means of deciphering a much more detailed history of the earth and its life than is the case in the earlier eras.

Imperfection of the Paleozoic Record. — Nowhere is there a complete record of Paleozoic formations, and even when the knowledge that has been gleaned from a study of all the North American exposures is pieced together, the record is still incomplete, though the gaps are not thought, as a rule, to represent long intervals of time. The longest array of superposed strata is to be seen in the area east of the Mississippi River, and in the Appalachians from northern Pennsylvania south to northern Alabama. When the formations here are studied in detail, and widely separated places are compared with one another, it is found that certain formations of one section may be greatly thickened or thinned or even completely absent in another (see Fig., p. 183). Even the famous sequence in the state of New York, the "Standard Section" with which the Paleozoic strata of America are compared and correlated, is now known to be very much interrupted by breaks or intervals of erosion.

CHAPTER XV

CAMBRIAN TIME AND THE DOMINANCE OF TRILOBITES

Part I. Cambrian in General, and the Lower Cambrian

Origin of the Term Cambrian. — The Cambrian period of time or system of rocks takes its name from Cambria, the Roman name of northern Wales, where the deposits were first studied by Professor Sedgwick of Cambridge University in 1822. The term Cambrian, however, proposed in 1835, was intended to apply to what is now called the Ordovician (Champlainian) period, the one following the Cambrian, and although Sedgwick often objected to the transposition, brought about in the main by his friend Sir Roderick Impey Murchison, this misapplied usage has unfortunately persisted.

Fig. 58. — Adam Sedgwick, at the age of forty-seven. Author of Cambrian and Devonian systems.

In Bohemia there is no Lower Cambrian, but Middle Cambrian is well developed, and here, through the great industry of a Frenchman, Joachim Barrande, who spent the greater part of his life as an exile at Prague, the sequence and abundant life of this time were made known. The fossils came to be widely spoken of as the "Primordial Life." Finally, a still more complete fossiliferous sequence was determined in Sweden and later in Newfoundland and these areas became standards for international correlation. However, nowhere is there a longer or a more complete sequence of fossiliferous Cambrian formations than in the Cordilleran region of North America, and to-day, due almost wholly to Charles D. Walcott, these are our chief standards of correlation.

Significant Things about the Cambrian Period. — The Cambrian period is the first one in the Paleozoic era, and is generally separated from the older rocks by one of the most marked unconformities known, representing a very long erosion interval. It is also the first period in earth history with an abundance of life preserved as fossils. This life consists entirely of marine invertebrates, and includes representatives of all of the more fundamental types, thus implying a long antecedent evolution. There is no trace of land animals, or of land plants, although the latter may have been present.

Still another striking fact about the Cambrian period is that the Cordilleric and Appalachic sinking areas, or geosynclines, are now fully formed seaways. Following the geosynclinal seas of Lower Cambrian time came marked spreading of these waters across the continent as epeiric seas, beginning in the late Middle Cambrian and attaining greatest flooding in early Upper Cambrian times.

Finally should be pointed out the striking topographic fact that when the Lower Cambrian seas entered the Appalachic trough from the south, their waves broke to the east against a mountain tract as grand as the present Alps of Europe. Like all mountains, however, their lofty beauty lasted but a short time geologically, and the close of the Lower Cambrian found them reduced to lowlands (see map, p. 193).

Cambrian Life. — Of Cambrian animals, it is estimated that about 1200 have been described from North America alone. From all countries together there are known not less than 1500 species, fully 90 per cent of which are trilobites and brachiopods, the trilobites making up about 60 per cent of the Cambrian faunas, and the brachiopods about 32 per cent. While this life is primitive in organization, its elements are so diversified as to indicate at once that it had a very long previous history. It is almost wholly a life with locomotive freedom. In the succeeding chapters we shall see that the marine invertebrates become more and more fixed to the ground, tending toward what John M. Clarke has recently termed "dependent life," which gives rise to no higher classes of animals.

Absence of all Land Life. — Not the slightest evidence exists showing the presence of land plants in Cambrian time, and the same statement is applicable to the greater part of the succeeding Champlainian. When, however, we consider that only the lower types of land plants could then have existed and that these were soft and nearly devoid of woody material, the only preservable portion, there is nothing extraordinary in this extreme imperfection of the plant record. On the other hand, the thoroughly decomposed

nature of the soils of this time, as seen in the mudstones largely made up of kaolin, appears to indicate that the lowlands at least must have been clothed with vegetation.

There is also not a trace of land animals, either of fresh waters or of the dry lands, in the Cambrian. The first clearly ascertained evidence of such does not appear until Silurian time.

The Lower Cambrian

The Lower Cambrian is restricted in eastern North America to the Appalachic geosyncline and its rocks will be referred to as the *Taconian series*. The strata of the Cordilleric geosyncline in western North America are embraced under the term *Waucobian series*.

The Term Taconian. — It is one of the glories of American Geology that the oldest Paleozoic rocks were first pointed out by a member of the great New York State Survey, Professor Ebenezer Emmons. The unravelling of the Taconian began in 1837, and Emmons' announcement of it as a system was made in 1841, and was followed by a different definition in 1842. But American geologists for more than half a century would not accept his system, because the Taconic Mountains of eastern New York, its type area, are in one of the most difficult regions possible for interpretation. Here the strata are not only closely folded and repeatedly over-thrusted, but have been much altered in the making of the mountains, so that their present condition is one of almost hopeless confusion. This difficult field condition was further enhanced by the various interpretations of the geologists of the time. It is only in recent years, through the growth of our science from facts garnered in all parts of the world, that a greater unanimity of opinion has come about, and some of the Taconian formations have been seen actually to have the age relations that Emmons attributed to them. He held that the Taconian rocks are older than the Potsdam sandstone, a formation now referred to the uppermost Cambrian, and that they are at the base of the Paleozoic series, conclusions that are true at least in part. It is on this residuum that the validity of the Taconian rests, and it must be recognized as at least a series term in good standing.

The Taconic controversy is well set forth by George P. Merrill in his interesting book, *The First One Hundred Years in American Geology* (Yale University Press, 1924).

Taconian Sediments. — In the Appalachic trough the Lower Cambrian thicknesses in places are great. In Vermont and northeastern New York there appear to be about 1500 feet, mainly of slate and quartzite, with an additional 1200 feet of marble and dolomite. This material was very largely derived from the west. In eastern Pennsylvania, western Maryland, and Virginia there are from 1000 to 5000 feet of limestone at the top with 4700 feet of sandstone and shale below. Keith thinks that all these sediments also came from the west, but farther south in the trough the deposits (Ocoee) came from the east.

Waucobian Formations. — In the Cordilleric sea the Lower Cambrian had by far the best development. Here Walcott has measured sections of strata ranging from 1500 to 5670 feet in thickness. The greater lower portion consists

usually of almost unfossiliferous sandstones and it is above in the shales and limestones that the fossils are common. All of this material came from the western land Cascadis.

Walcott tells us that in the Cordilleric trough the Cambrian sediments are often the Proterozoic residuals worked over by the advancing Paleozoic sea and deposited almost conformably on the underlying and geologically undisturbed Proterozoic formations. In such instances, where the waves and current action were weak, the passage between the strata of the Proterozoic and Paleozoic is almost imperceptible and often could not readily be distinguished if it were not for the abundant remains of animal life in the Cambrian. Nevertheless, there is a time break here of vast duration. It may, however, be said that as a rule the sandstones of the Proterozoic are dirty and rich in feldspars, and it is the greater or complete absence of the latter in the Cambrian sandstones that helps to distinguish them from the older ones.

The Early Cambrian Ocoee Mountains. — In northwestern Georgia, eastern Tennessee, and western North Carolina, the strata known as the Ocoee and Chilhowee series have long perplexed geologists as to their geologic age. They form a most interesting series of formations highly variable in character and thickness from place to place, and consist in the main of thin and very thick conglomerate zones wedging in and out of a vast pile of feldspathic sandstones that have but few mudstones and least of all limestones. The average thickness in an area of over 200 miles long by 30 miles wide ranges between 9000 and 13,000 feet. After much arduous labor in the field, Arthur Keith, on the basis of field relations and fossils found near the top of the series, was finally able to demonstrate their age as Lower Cambrian.

These coarse materials of the southern Appalachic trough, Joseph Barrell, in an unpublished manuscript, states came from a highland area that then stood to the east, and one not at all unlike the present Alps. The mass of rock which was eroded to furnish what is now seen in the Ocoee and Chilhowee series he estimates was equivalent to a block 200 by 30 miles in extent, and 28,500 feet thick. The Ocoee mountains stood where the Piedmont plateau now is.

The local climate is thought to have been cool, with a moderate rainfall, but there is here no evidence of a glacial climate or even of local glaciers.

Into the valleys of this eastern highland the early Taconian sea flooded, drowning their western ends (see map, p. 193). Early in this sea-invasion the rivers were of the torrential type, and deposits coarse in character rapidly filled the drowned river valleys. More than two thirds of the unfossiliferous Ocoee-Chilhowee series is of fresh-water origin, and it is only toward the top of these formations in widely spread shales and cleanly washed sandstones that a few marine fossils of late Lower Cambrian age have been discovered.

Life of the Lower Cambrian. — The known life of the Lower Cambrian is wholly of the seas. This animal life, consisting en-

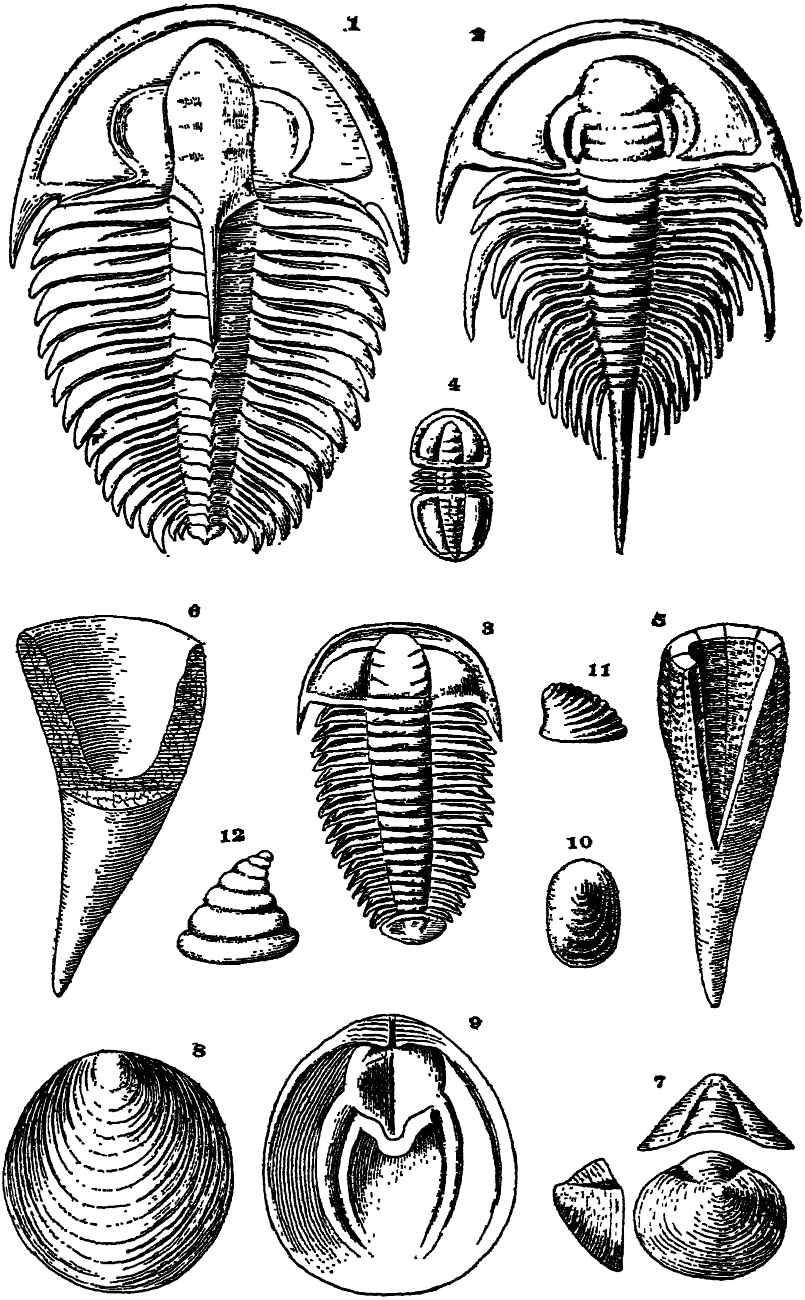

Plate 4. — Lower Cambrian trilobites (Figs. 1–4), gastropods (10–12), brachiopods (7–9), and corals (5, 6).

Fig. 1, *Holmia bröggeri*, $\times \frac{1}{3}$; 2, *Olenellus thompsoni*, $\times \frac{1}{2}$; 3, *Atops trilineatus*; 4, *Eodiscus speciosus*; 5, *Archæocyathus rensselæricus*, $\times$ 3; 6, *A. profundus*; 7, *Paterina bella*, $\times$ 4; 8, 9, *Obolella crassa*, $\times$ 3; 10 to 12, *Stenotheca rugosa*. All after

tirely of marine invertebrates, ranges from simple sponges to complex forms of Crustacea. This statement does not, however, imply that all of the known kinds of invertebrate animals, fossil and recent, were already represented in the Lower Cambrian, only that the main stocks, the phyla of the scheme of classification, were here in well developed forms. More than one half of the common animals are trilobites (crab-like forms fully described in a later chapter), and 32 per cent are brachiopods (two-shelled animals without pearly shells, described in Chapter XVII). As the former are the characteristic and most common fossils of the Cambrian, we speak of them as the dominant animals of this time. See Pls., pp. 189, 201. The life of the Lower Cambrian seas is very much alike not only throughout America, but in Europe, Asia, and Australia as well. It is therefore said to be *cosmopolitan* in character.

The trilobites were, as has been said, the most characteristic animals of the Lower Cambrian. Nearly all of the many brachiopods had shells made of phosphate of lime, while those of the later Cambrian and subsequent periods were of carbonate of lime. The limpet-like gastropods (shells like the snails, drills, and periwinkles) were rare and of the most primitive type; with one exception, they were hood-shaped and not spirally coiled as is usually the case among these animals (Pl., p. 189, Figs. 10–12). The conical three-sided tubes known as *Hyolithes* were abundant (Pl., p. 201, Fig. 8). They are related to the gastropods. There were still other kinds of animals, but no mussel shells, and only the most diminutive and primitive cephalopods (*Salterella* and *Volborthella*).

One of the most interesting types of Lower Cambrian fossils is casts of jellyfishes (medusæ), whose original composition is 95 per cent or more water. The illustration (Fig. 19, p. 155) of a living *Aurelia* shows what these Cambrian jellyfishes looked like. They are common as fossils in Vermont and Alabama.

In the oldest of the Lower Cambrian deposits in California and Nevada, fossils are scarce and all that have been found are two forms of trilobites. Near the top of the Lower Cambrian, however, fossils are abundant and consist of trilobites, snail-like forms, brachiopods, and the coral-like Archæocyathidæ. In Inyo County, California, occur limestone reefs made up of these coral-like animals, and their fossils are found in many parts of the world: Labrador, with reef limestones up to 50 feet thick; New Siberia, in 70° north latitude; Sardinia; Spain; Australia, with limestones fully 200 feet thick, over an extent of 400 miles — the greatest Paleozoic reefs known anywhere; and finally in Antarctica.

Archæocyathidæ (from Greek words meaning *primal* and *cup*). — These are the most ancient and the simplest coral-like animals known, and are almost restricted to the Lower Cambrian (see Pl., p. 189, Figs. 5–6). They are rare in the earlier part of the epoch. In general, they are single polyps, though some are thought to be compound animals. Single polyps sometimes attain a length of 11 inches, while the saucer-like forms may be as wide. Their form is most often that of two cups placed one within the other, and their skeleton consists of granular calcite, not of spicules. The very deep inner cups are without spines or septa and are pierced with perforations, and the space between the two cups is more or less subdivided by radial partitions and horizontal bars or plates, which are also perforated, the pores being arranged in longitudinal series. In other forms the outer wall may be thick and porous, or have worm-like canals. The basal attachment of the corallum is also more or less thickened by vesicular partitions.

The archæocyathids have been compared with calcareous algæ, such as living *Acetabularia*, but in general their skeletons approximate more closely that of the Anthozoa, though in general shape, protean forms, and methods of attachment they are distinct from the usual cœlenterates and in certain characters they resemble the sponges. According to some writers, they appear to hold an intermediate position between the corals and the sponges, by others they are regarded as sponges, but in this book they are looked upon as more probably belonging to the cœlenterates.

Significance of Lower Cambrian Life. — As trilobites, which belong to the highest division of invertebrate animals and are therefore really complex organisms, were the dominant life of the Lower Cambrian, it is plain that life could not have originated in this time. Even though it is now established that a variety of animals must have been present in the Proterozoic, still the change in the life of the Lower Cambrian, as compared with that of the former era, is very remarkable. We have seen that in the Proterozoic the known organisms are essentially lime-secreting seaweeds and worm tubes made of chitin, yet in the Lower Cambrian there was an abundance of very varied and highly complex animals with skeletons of chitin and carbonate of lime. These facts mean, on the one hand, that there is a very great loss of record in the geologic column between the latest Proterozoic and the oldest Cambrian deposits, and on the other hand, that since the time of the Proterozoic, invertebrate animals had taken upon themselves an external skeleton, either of chitin or carbonate of lime.

Marine Life Zones of Lower Cambrian. — On the basis of characteristic trilobites, the Lower Cambrian is divided into five life zones. The oldest — (1) Nevadia zone — is restricted to the Cordilleric trough; the next three — (2) Elliptocephala zone, (3) Callavia zone, (4) Olenellus zone — are common to this and the Appalachic trough; while the youngest one — (5) Protolenus zone — is restricted to the Atlantic province of Cape Breton.

Lower Cambrian Paleogeography. — The paleogeographic map of the probable seaways of this time is shown on p. 193. We know that the Pacific Ocean in earliest Lower Cambrian time first invaded the land in the Great Basin area and gradually spread northward, forming throughout the Cordilleric geosyncline a sea which finally united with the Arctic Ocean. Some time after the appearance of the western Cordilleric sea, a similar waterway appeared to the west of Acadis and Appalachis, finally extending as a narrow trough — the Appalachic geosyncline — from Alabama to southeastern Labrador. At its maximum the Lower Cambrian inundation did not submerge more than 18 per cent of North America.

The North American continent then, as now, was bordered by highlands, but these lands extended out into the oceans hundreds of miles farther than do the present shore-lines. On the west was the extensive land of Cascadis, and on the east were two land masses, the southern and greater one being Appalachis united with Antillis, which was more or less continuous with the northeastern one, known as Acadis. It was from these marginal highlands that came nearly all the sediments of the inland seas, the exception being in northern Appalachis, where the débris came from the west. The greater northern half of North America, the Canadian Shield, was also land, but it was a low land and furnished only a small part of the sediments of Cambrian time.

Lower Cambrian Climate. — From the world-wide distribution of the reef-making coral-like animals of this time described on a previous page, it is evident that the waters of at least the later half of the period were warm and equable over most of the earth, since these animals lived then not only in the equivalent temperate regions of the present but also in both polar areas. Then, too, the wide occurrence of limestone-depositing seas in the succeeding Cambrian, with an even greater abundance of varied life, is further evidence of mild climate over most of the world, not only for Lower but as well for all Cambrian times.

It should be pointed out once more that the so-called "Lower Cambrian" tillites of eastern Australia, and the feldspathic (Sparagmite) series of the "Eo-Cambrian" of central Norway are not clearly established as of the time of the Lower Cambrian. They are for the present better referred to the Proterozoic, and in Chapter XII are discussed at greater length. However, even if the evidence of these tillites is admitted to denote Lower Cambrian, there would still be time enough for the oceanic waters to have again become warm by the time of the appearance of reef limestones made by the Archæocyathidæ.

Lower Cambrian Emergence. — Toward the close of the Lower Cambrian, the Appalachic geosyncline was drained of all of its

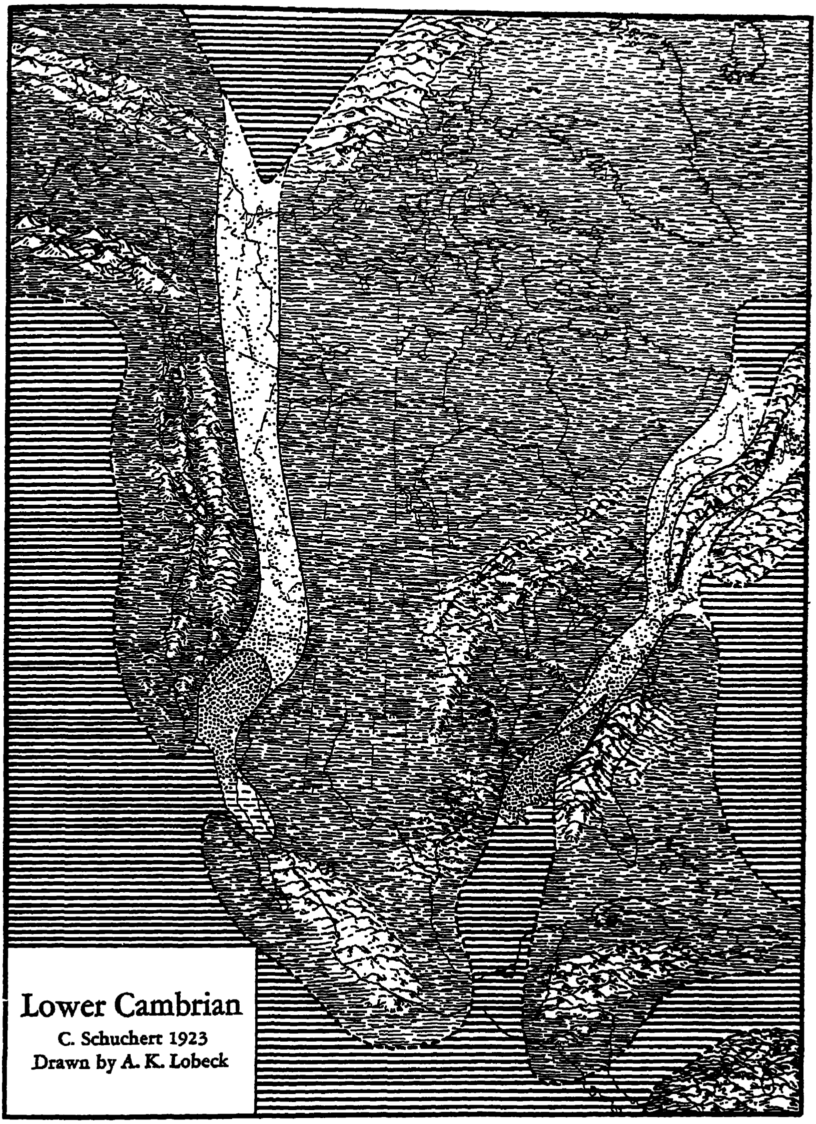

Plate 5. — Lower Cambrian paleophysiography

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 6 (p. 195) for Cambrian paleogeography.

The probable geography of Lower Cambrian time, without most of the drainage, which is wholly unknown. The seas are described on page 192, and the map shows the earliest and latest floods. The Ocoee mountains of Appalachis are described on page 188, and the Killarney mountains of Ontario on page 171. The other mountain areas of this time are more or less hypothetic.

The land was devoid of all vegetation, and the climate mild and more or less arid.

marine waters, and a long time ensued before another cycle of deposition took place in this trough. What took place at this time in the Cordilleric geosyncline is not clear. In the most continuous area of Cambrian deposition — Mt. Bosworth, British Columbia — Lower Cambrian fossils are present to the top of the Mount Whyte formation, then for 500 feet there are no fossils, and above comes an unmistakable Middle Cambrian fauna (Albertella fauna). Walcott holds that there is continuous deposition here and expects transitional faunas to turn up in this 500-foot interval of arenaceous limestones, uniting the older ones with those of the Middle Cambrian.

As previously stated, at the close of Lower Cambrian time the Appalachic geosyncline was drained of its marine waters, and the sea did not reënter it until Upper Cambrian time.

Part II. The Middle and Upper Cambrian

Physical Characteristics

During Middle and Upper Cambrian times most of North America appears to have been a lowland devoid of scenic beauty. Accordingly it was possible for the oceans to transgress the lands widely, as we shall see they did. If there were any highlands at all, they were in the bordering lands of Cascadis, Appalachis, and Acadis. In the center of the great interior lowlands stood a low upland consisting of the roots of the Killarney Mountains (see p. 193) that trended east and west across what is now the Lake Superior country.

The longest and most complete Cambrian sequences of strata with entombed fossils occur in the Cordilleran region of North America, and here it is believed there was continuous deposition throughout the Cambrian period. From the Middle into the Upper Cambrian all stratigraphers are agreed that the seas continued uninterruptedly, and a few even hold that there was in most places an unbroken recording of strata and fossils into the Champlainian (Ordovician). The latter view is, however, not yet established.

Close of the Middle Cambrian. — In all places where the Upper Cambrian strata repose on those of Middle Cambrian time it is seen that the life of the one series is as a rule sharply distinguished from that of the other; in other words, there are no known transition faunas of this time in eastern America preserving the stages of evolving forms, and this is thought to indicate a break in deposition and

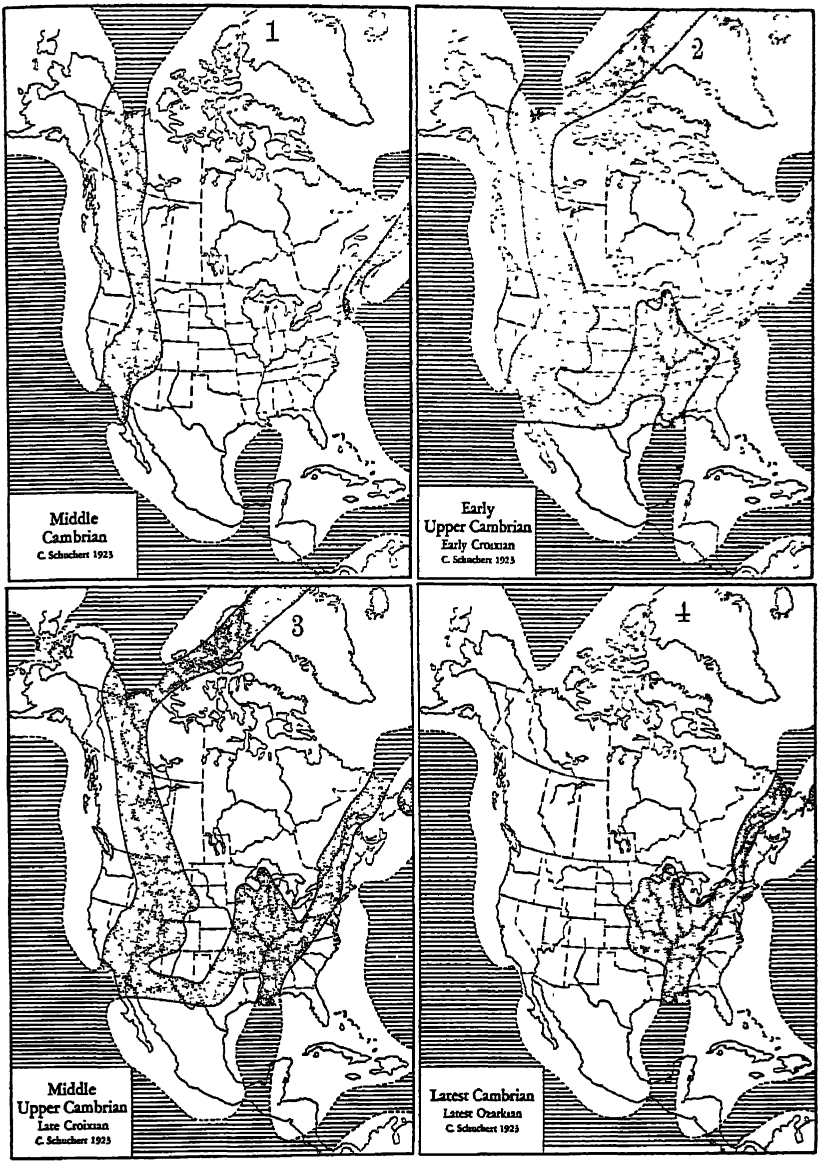

Plate 6. — Paleogeography of Cambrian time.

Epeiric seas dotted; oceans ruled. See Plate 5 (p. 193) for Lower Cambrian physiography.

Note that the Cordilleric, Franklinic, and Appalachic geosynclines are in full development at this early time. The Acadic geosyncline had water in it only in Lower and Middle Cambrian time.

an absence of faunal record. Only in the Cordilleric trough occur transition faunas; in the greater part of the Appalachic geosyncline the Upper Cambrian rests on the Lower Cambrian with all of the Middle Cambrian absent. This is evidence that in the latter region the elevation brought about by the Lower Cambrian emergence had not yet been overcome by erosion or subsidence. However, there are so far no data showing that either Appalachis or Cascadis had been further elevated at the close of Middle Cambrian time.

Inland Seas. — During the Lower Cambrian, the seas were restricted to the Cordilleric and Appalachic geosynclines, but in Middle Cambrian time the latter trough was drained of all marine waters. The Cordilleric geosyncline, however, continued its seaways throughout Middle and Upper Cambrian time, laying down from 5000 to 8000 feet of usually thin-bedded limestones, but very little shale and almost no sandstone.

Late in the Middle Cambrian the Cordilleric marine waters began for the first time to spread across the continent toward the east, and throughout most of Upper Cambrian time epeiric seas were of wide extent, especially in the area of the Mississippi basin. In the Arbuckle Mountains of Oklahoma there is no less than 3000 feet of limestones and dolomites. The Appalachic trough was also reoccupied by these waters of Pacific origin, depositing magnesian limestones with some shale. In Alabama the thickness is about 4000 feet, and this depth remains fairly constant all the way north to Chambersburg and Mercersburg, Pennsylvania. When the flood was at its widest, it covered more than 30 per cent of North America (Pl., p. 195, Fig. 2).

Croixian Seas. — The early Upper Cambrian is also known as the *Croixian epoch* (pronounced Croyan; from the St. Croix River of Wisconsin), and in the upper Mississippi valley sandstones and not limestones are the dominant strata. Here these sandstones are wide-spread and in Wisconsin their thickness is about 720 feet. They are the residual materials or the loose rock and soil (regolith) of a granitic lowland, the Canadian Shield, that had for a very long period undergone erosion. These sands are usually well rounded with lusterless surfaces, and hence are thought to be the sands of ancient deserts or at least of dunes rewashed into the deposits of the Croixian series. In small amounts these sands reach as far as the Ozark region of southern Missouri, where the Upper Cambrian deposits are thin and consist mainly of limestones alternating with sandstones.

The Croixian seas were prevented from spreading north of the region of Lakes Superior and Huron by the east-west trending Killarney Mountains that came into existence late in Proterozoic time (Collins 1922). They were not reduced to a peneplain until late in Champlainian (Ordovician) time, since the sediments of the Richmondian were the first to transgress them.

It may be well to state here the formations included by Ulrich in the Croixian epoch of the upper Mississippi Valley: Mt. Simon, Eau Claire, Dresbach, Franconia-Mazomanie, St. Lawrence, and Jordan.

Some geologists think that the upper Keweenawan and Lake Superior sandstones are river deposits of Croixian time, but as yet the proof is not at hand for this correlation.

Ozarkian Epoch. — The late Upper Cambrian constitutes the Ozarkian epoch. In 1911, Ulrich proposed this name (from the Ozark uplift in southern Missouri) for a series of formations that had heretofore been referred mainly to the Cambrian and in part to the Champlainian. Walcott accepted Ulrich's conclusions in 1923, regarding the Ozarkian as the final series of the Cambrian, and it is so placed in this book.

The early Ozarkian sea invaded the central part of the continent from the south, and at about the same time spread into the Appalachic geosyncline. The Cordilleric trough was also invaded. During the late Ozarkian the seas were greatest in the Mississippi Valley and the southern Appalachic trough. (See p. 195.)

As a rule, Ozarkian fossils are scarce, or at least hard to get, because most of the formations are dolomitic, and yet Ulrich has about 200 species. Walcott (1923) lists 125 forms alone from the older Ozarkian and of these about 70 are trilobites, 25 brachiopods, 20 gastropods, 4 cephalopods, and 2 bivalves. The most prevalent organisms are lime-depositing seaweeds (*Cryptozoōn*, see Fig., p. 198).

In Missouri, the Ozarkian series is mainly of the later half (Gasconade, Proctor, and Eminence, with a combined thickness of 525 feet), while the earlier portion is only partially present in the Potosi formation (300 feet). In Wisconsin, the thin Madison and Mendota are below, then comes a long break, and at the top is the Oneota. In eastern New York, the Little Falls, Hoyt, Theresa, and Potsdam constitute the lower Ozarkian; their equivalents Keith has shown to be also present in northern Vermont. In central Pennsylvania, the lower Ozarkian has a thickness of 2250 feet. The longest and thickest development, 5550 feet, occurs in Alabama. In Nevada, the Goodwin formation is 1500 feet thick, while the St. Charles of Utah, and the Chushina and Mons of Alberta have similar depths. The Cordilleran formations are all of early Ozarkian time.

Fig. 59. — Glaciated surface of the "Cryptozoön Ledge" of the Hoyt formation, at Lester Park, near Saratoga Springs, N. Y. Photograph by H. P. Cushing, N. Y. State Survey.

At the close of the Upper Cambrian, there appears to have been a very wide and probably a complete retreat of the epeiric seas from the interior parts of North America.

Establishment of the Lime-secreting Habit. — The epeiric seas of Middle and Upper Cambrian time, as we have seen, deposited a very great amount of rocks consisting of carbonate of lime; this means not only that the waters were clean of muds but that their temperature was warm as well. Life was more prolific in the Upper Cambrian and there was also an abundance of invertebrate animals with lime carbonate skeletons. In other words, for the first time

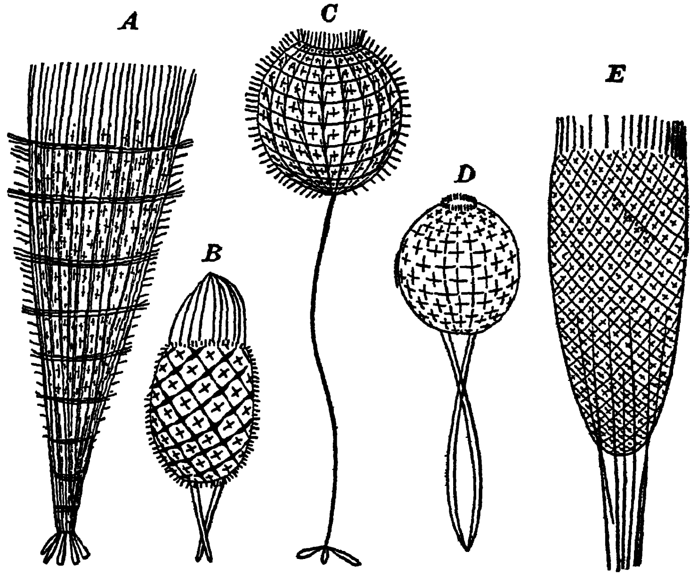

Fig. 60. — Five species of "glass sponges" (*Protospongia*), from the Upper Cambrian (Ozarkian) at Little Metis, Quebec. Similar living forms are known as "Venus' flower baskets." After Dawson and Hinde.

in the history of the earth there was an abundant molluscan fauna, and the greater abundance of carbonate of lime in the seas established the lime-secreting habit permanently in many classes of animals.

Life of the Middle and Upper Cambrian Epochs

The seas of Middle and Upper Cambrian time swarmed with a great variety of life, chiefly trilobites and brachiopods. In the Upper Cambrian the gastropods begin their ascendency, and the same is true of the cephalopods, though to a less striking degree. The bivalved molluscs and crustaceans, the lamellibranchs and ostracods make their appearance in the Ozarkian epoch.

Beginning with the Middle Cambrian, instead of the cosmopolitan faunas of the preceding epoch, there are now clearly two realms, the greater one of the Pacific, recently named *Albertan* by Grabau, and that of the North Atlantic, first developed by G. F. Matthew from the region about St. John, New Brunswick, and named *Acadian* by James D. Dana in 1874. During Middle Cambrian time the Cordilleric sea had about the same limited geographic extent as that of the Lower Cambrian, while most of the Appalachic geosyncline appears to have remained continuously above sea-level.

Albertan Faunas of the Cordilleric Sea. — The western or Cordilleric limestone-making seas were prolific in life. The faunas of the Albertan seas were distinctly of the Pacific realm, similar ones

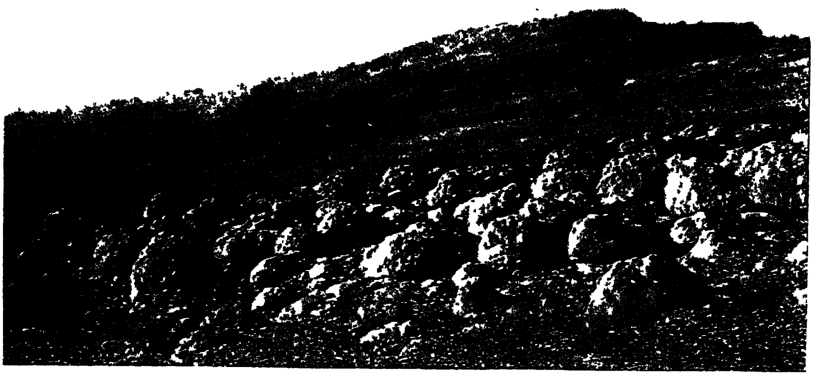

Fig. 61. — Algal growths weathered out of Upper Cambrian shale in the divide between North and South Leigh creeks, Grand Teton quadrangle, Wyoming. Photograph by Eliot Blackwelder.

being known in China. Trilobites were dominant, making at least half of the faunas, and there was a greater variety of these interesting animals than in the Lower Cambrian (Pl., p. 201, Figs. 1–4). Large-tailed forms were characteristic of the Pacific waters, and as the genus *Bathyuriscus* was the most prevalent form at this time, these waters are sometimes called the Bathyuriscus realm. The brachiopods were also far more numerous than in the Lower Cambrian, but still small, and almost all of them not only had phosphatic shells but were very similar to those of the preceding epoch.

The fauna of the Cordilleric trough was marked by the trilobites *Olenoides, Albertella, Dorypyge, Neolenus, Ogygopsis, Asaphiscus,* and *Bathyuriscus,* and

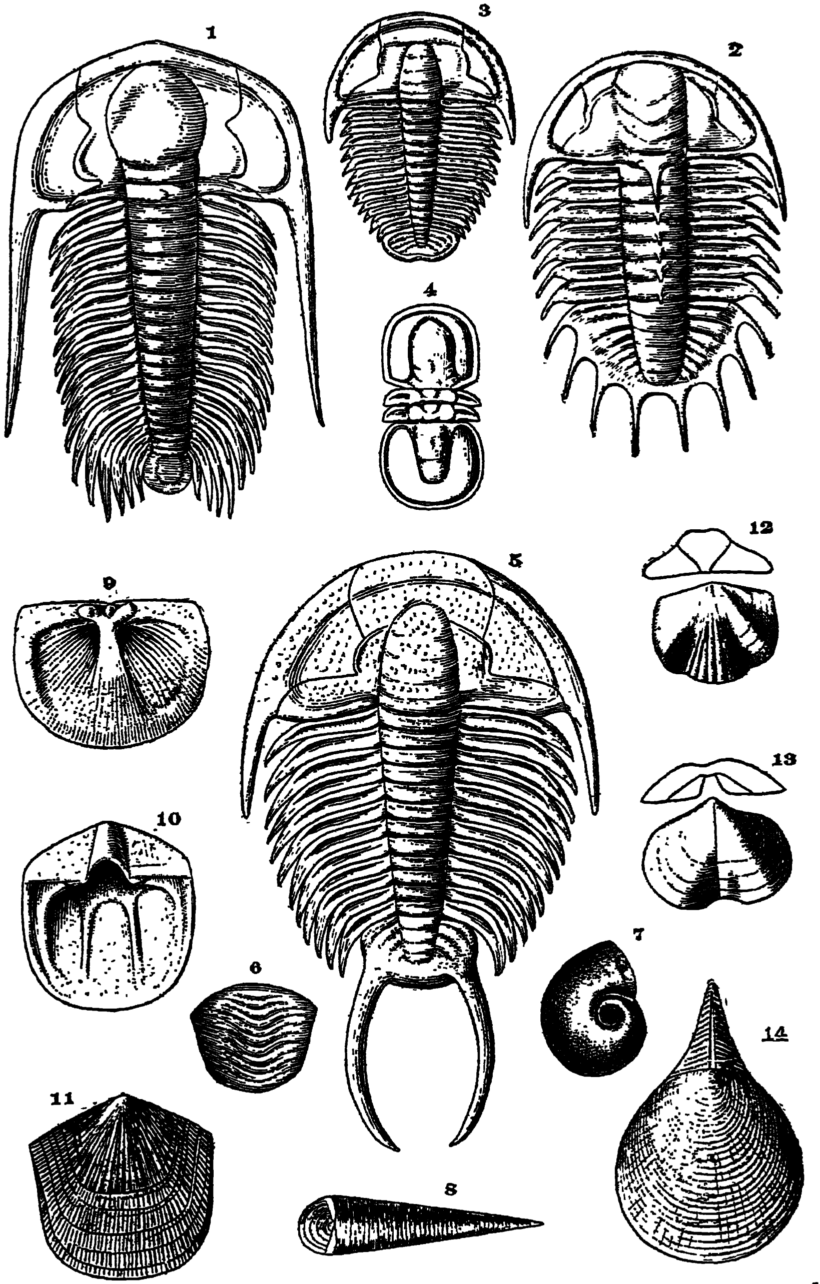

Plate 7. — Middle (1–4) and Upper (5) Cambrian trilobites, gastropods (6, 7), pteropod (8), and brachiopods (9–14).

Fig. 1, *Paradoxides harlani*, $\times \frac{1}{4}$; 2, *Dorypyge curticei*, $\times \frac{1}{2}$; 3, *Ptychoparia kingi*, $\times \frac{3}{4}$; 4, *Agnostus montis*, $\times 3$; 5, *Crepicephalus texanus*, $\times \frac{1}{3}$; 6, 7, *Owenella antiquata*, $\times 2$; 8, *Hyolithes primordialis*; 9–11, *Billingsella coloradoensis*, $\times 2$; 12, 13, *Huenella texana*, $\times 1\frac{1}{2}$; 14, *Lingulepis acuminata*, $\times 2$. Mostly after Walcott.

by the brachiopods *Lingulella*, *Micromitra*, *Acrothele*, *Nisusia*, and *Billingsella*. *Hyolithes* was common and there was a somewhat greater variety of gastropods.

Burgess Shale Middle Cambrian Fauna. — In the Selkirk Mountains of British Columbia, famed for scenic grandeur and for alpine glaciers, has been found the most interesting locality in the world for fossil invertebrates. The mountains here are made up largely of Cambrian strata, which attain a thickness of at least 13,000 feet. The Burgess fossil community lies in a bed of hardened Middle Cambrian shale some 7 feet thick, situated on the southwestern flank of Mt. Wapta, about 3000 feet above the town of Field, and 8000 feet above sea-level. This wonderful cemetery of ancient sea animals was discovered in 1910 by Walcott, who has since quarried out hundreds of tons of rock (100 x 15 x 7 feet) that have netted him thousands of specimens, described under 70 genera and 130 species. The striking feature of the fauna is that the usual Cambrian forms, especially brachiopods and molluscs, are rare, while the common fossils are of soft-bodied creatures such as worms, etc., or chitin-covered crustaceans other than trilobites, stocks seldom seen anywhere by the paleontologist. All in all, it is a revelation of how very imperfect our knowledge is of the faunas of the past; what we have are but the " skimmings of the pot of time."

Fig. 62. — Charles Doolittle Walcott (1850–). The leading student of Cambrian faunas and their sequence.

Nearly all of the Burgess forms were devoid of calcareous external skeletons, and where there was a hardened covering it consisted in the main of chitin. It is natural to ask, therefore, Why were these usually thin-shelled and often soft-bodied animals preserved in the Burgess shale, while elsewhere the mud bottoms of the same age failed to retain traces of the organisms of their time of deposition? The Burgess shale is a blue-black, bituminous, aluminous mud with quartz of finest grain and some iron pyrite; it was probably laid down either in a depression of the sea bottom, a mud hole, or in a more or less enclosed bay

where the currentless waters were stale and devoid of free oxygen. On such foul bottoms, reeking with carbonic acid, and lacking in oxygen, no animals can live except sulphur bacteria. However, almost none of the Burgess shale organisms were types which lived on the bottom, but they were almost all floaters and swimmers, inhabitants of the surficial sunlit and oxygenated sea waters. We must therefore conclude that they represent the life of the surficial waters which dropped into the asphyxiating death-trap near the bottom. These foul bottoms had no scavengers to eat the moribund, nor were there here the usually prevalent decomposing bacteria to destroy the organisms that fell from above into the very soft muds. Hence the bodies were quickly covered by the fine muds and underwent a slow chemical alteration, leaving behind a residuum, often as "fools gold," or pyrite, which preserves in greatest detail the forms of the organisms entombed.

The Burgess fauna includes a varied array of siliceous sponges (monactinellids and hexactinellids). There is one jellyfish (scyphomedusan) and a remarkable variety of annelids preserving the entire body form. The most interesting organisms, however, are the crustaceans, twenty-eight genera of branchiopods, phyllocarids, primitive and specialized trilobites, and other generalized subclasses suggestive of links between some of the crustacean and arachnidan phyla. Curiously, no ostracods are known here or elsewhere until latest Cambrian time, but the forms so called are in reality phyllopods. Often the soft parts and the limbs are preserved, and there is even much structure at hand that reveals something of the internal organs (see Fig. *B*, p. 211).

Acadian Faunas of the Atlantic Area. — In the Acadian region and in Newfoundland, there are other Middle Cambrian deposits, here essentially muds and sands, with distinctly different fossils, though of the same general faunal development as those of western Europe, in other words, of the Atlantic realm. They are characterized by the trilobite genus *Paradoxides* (Pl., p. 201, Fig. 1).

The trilobites of the Upper Cambrian, now more varied than before, made up over 50 per cent of the faunas (Pl., p. 201, Fig. 5), while the brachiopods with phosphate of lime shells were at the height of their development, and those forms having valves of carbonate of lime (Pl., p. 201, Figs. 9–13) were rapidly increasing. Then there were also a number of coiled and spiral gastropods (Pl., p. 201, Figs. 6, 7), and a few cephalopods of the pearly nautilus type as well.

Characteristic Fossils of the Croixian. — The more characteristic trilobites of the Central Interior sea and of the Cordilleric trough were *Dikellocephalus*, *Saukia*, *Illænurus*, *Conaspis*, and *Crepicephalus*. The earliest limulid (horseshoe crab) is present in *Aglaspis* and a eurypterid in *Strabops*. Of brachiopods there were *Linnarssonella*, *Lingulepis*, *Obolus*, *Syntrophia*, and *Billingsella;* of gastropods, *Owenella*, *Holopea*, and *Pleurotomaria*-like forms. Bottom-living graptolites made their appearance here in *Callograptus*.

Green Mountains Disturbance

At the close of the Cambrian the New Brunswick geanticline (see p. 141) was reëlevated and in Vermont and Quebec the Cambrian limestones were locally broken up to furnish the material for the thick and much localized limestone conglomerates (Beekmantown) at and near the base of the Champlainian. The fragments of these conglomerates are angular to subangular and rarely rounded; often the pieces are large, up to one or more tons in weight, while in Quebec and Vermont occur masses up to 150 feet in length. Some of these conglomerates have been interpreted as intraformational

Fig. 63. — Unconformable contact between Archeozoic marble and uppermost Cambrian (Potsdam) sandstone, 10 miles northeast of Kingston, Ontario. Photograph by Jesse E. Hyde.

in character, but are now known to be true conglomerates and breccias, since they have both Lower and Upper Cambrian fossils. The conditions under which they were made are not yet clearly understood, but they appear to be rock slides of cliff origin, the St. Lawrencic sea of early Champlainian time having undermined the cliffs, causing great masses of them to fall into the marine depths.

One of the striking facts in connection with this disturbance is the absence of early Champlainian formations in most of Nova Scotia, northern New Brunswick, and all of the New England States other than Vermont and western Massachusetts and Connecticut. These areas are the region of the New Brunswick geanticline, a highland that furnished the sediments and conglomerates for the

northern part of the Appalachic geosyncline of Champlainian time (Beekmantown). For easy reference, this time of land elevation at the very close of the Cambrian may be comprehended under the term *Green Mountains Disturbance*, since the Green Mountains are situated on the western border of the uplifted area.

There was also some elevation of the lands in western Europe previous to earliest Champlainian time. Holtedahl in 1920 writes of the rising of a vast northern land (northern Fennoscandis or the northern side of the Baltic Shield) at some time towards the close of the Cambrian and before the introduction of the Champlainian.

In the previous edition of this text-book it was stated that "Apparently the closing epoch of the Upper Cambrian was a time of quiet emergence and withdrawal of the sea." Further, that "There was no mountain making at this time in North America." Since this was written, the unravelling of the very difficult geology of Vermont has made much progress and it now appears that there was some crustal movement in the area of the New Brunswick geanticline. The facts on which these conclusions are based are as follows: The recent work of Arthur Keith west of the Green Mountains of northern Vermont has shown that this region was either folded or vertically uplifted at the close of the Cambrian, that is, after Ozarkian time. Here the basal Champlainian conglomerates consist in the main of thin-bedded limestones and large blocks of a white marble. In some of the limestone bowlders occur Lower Cambrian fossils, but more commonly they are of early and late Upper Cambrian kinds. As the pieces are in the main angular and of all sizes, and clearly from Lower and Upper Cambrian formations, the evidence of the conglomerate appears to indicate that their sources were highlands shortly to the east, and that the transporting power may have been cliffs facing the sea.

In the area about Quebec, the Champlainian begins with thick unfossiliferous formations of coarse and conglomeratic quartz sandstones (Lauzon), followed by red shales (Sillery). Then come the Levis dark shales, with thin zones of limestones, having an abundance of Beekmantown fossils, and many zones of limestone conglomerates, the pieces of which have Cambrian fossils. These occurrences may be traced from Quebec along the south side of the St. Lawrence River northeastward for at least 200 miles, and at Bic the conglomerates are in grandest development.

Collateral Reading

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CHAPTER XVI

TRILOBITES

(See Pls. 4, 7, and 12)

History. — Trilobites were the first fossils to attract the attention of naturalists and have long been of popular interest. It was Lhywd, the curator of the Ashmolean Museum at Oxford, England, who, in 1698, first called attention to an entire specimen. He did not know how to classify it but thought it was the skeleton of an unknown fish, and for a long time the animals were regarded as beetle wings, caterpillars, insects without wings, fossil butterflies, and even molluscs. The great Swedish naturalist, Linnæus, first correctly recognized their relationship with the Crustacea, animals such as shrimps, crabs, and lobsters. Professor Walch of Jena, Germany, in 1771, gave them the generic name *Trilobites*, a term that has since been raised to the rank of a subclass *Trilobita* of the class Crustacea of the phylum Arthropoda, which contains an exceedingly varied array of animals with articulate or segmented bodies and limbs, among them the crustaceans, insects, scorpions, and spiders. There are now more than two thousand kinds of trilobites known.

Definition. — The word trilobite means *three-lobe-like,* and has reference to the three longitudinal lobes (the central *axis* and lateral *pleura*) seen on the dorsal or upper side of most trilobites (see Fig., p. 208). They were sexed animals. Their bodies were made up of segments, many of which articulated upon one another; and these segments were gathered together into three divisions, as may be seen in any entire specimen of the upper shell or *carapace,* the part usually preserved. The under, or ventral side, with the limbs, had a very thin outer shell and was preserved only in exceptional conditions, usually in black, more or less sulphurous shales. The carapace was thicker, and made up of chitin (very much as in horn, hair, etc.), a nitrogenous substance to which is added more or less of lime salts. Chitin greatly resists chemical alteration, and this is the reason why trilobites are so often preserved as fossils.

Habits and Habitat. — Trilobites inhabited only marine, and in the main, shallow waters, and their tests or outer shells are found

in all kinds of marine sediments, but chiefly in shales and limestones. In general they were rather sluggish animals, floating readily, but swimming probably in a jerking manner, and particularly backward, either with the ventral or dorsal side up. Over the sea bottoms they crawled slowly with the aid of numerous stout legs. Some of them dug into the sand for living food, going in head

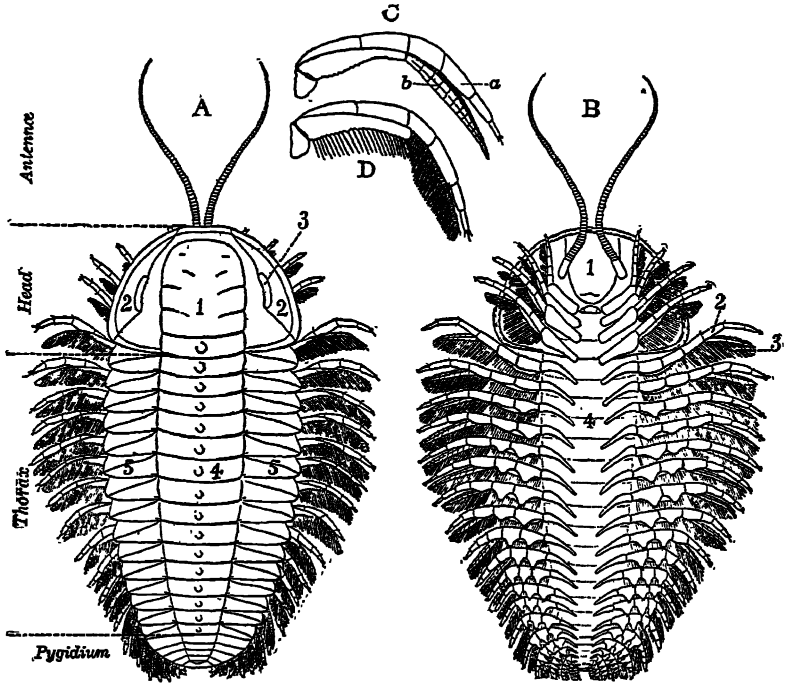

Fig. 64. — Sketches of a complete trilobite (*Triarthrus becki*). × 2. After Beecher. *A*, dorsal or upper side of carapace, showing three lobes, pleura (5), rachis or axis (4), glabella (1), and free cheeks (2) which bear the eyes (3). *B*, ventral or under side, showing biramous limbs (2, 3) attached to rachis (4), and upper lip or hypostoma (1) which covers mouth. *C*, one of the double legs, seen from above, stripped of setæ or breathing organs. *D*, another leg with setæ attached; the upper member of the leg is for breathing and swimming and the lower part for crawling.

first, while others entered tail first and thus concealed awaited their prey, darting after it suddenly in the manner of fishes. Still others groveled around eating the mud. The small species of highly spinous forms may have spent their lives floating and swimming in the plankton, while those with large eyes may have dwelt in the dark deeper parts of the seas, rising at night to the surface in search of food. Many trilobites, and particularly those of the Cambrian

of the Atlantic province, are said to have been blind, having no eyes, or certainly none on the dorsal side. Because of this blindness, they are thought to have lived generally in very deep or even abyssal waters, but the sediments in which they occur and the fossils associated with them indicate that they also lived in shallow seas.

Most trilobites could roll their bodies up like the sow-bugs or pill-bugs of our cellars, animals that are not insects but Crustacea (isopods) and distant relatives of the trilobites. This rolling up was for the protection of the softer and more delicate parts of the ventral side, thus presenting to the enemy the hard, thick carapace, an effectual armor against other trilobites but ineffective against the cephalopods and fishes. The power of coiling up first appeared in the Upper Cambrian, and with the Champlainian all forms had adopted such a method of protection.

As a rule, trilobites were carnivorous, and as scavengers kept the sea bottoms cleaned of their dead animals; some were omnivorous; others probably wholly vegetarians; and a few were "mud eaters," the digestive tract assimilating the organic matter in the muds for bodily sustenance.

In the early Cambrian, trilobites with large pygidia, or tail-pieces, began to be common, and this greater size, attained through the consolidation of a larger number of segments, is thought by some to have resulted from the use of the enlarged tail as a swimming organ by striking it rapidly downward and forward, causing the animals to dart backward as do the living crayfish and lobsters. The maximum of pygidial increase and the greatest abundance of forms having it were attained in the Champlainian. This tendency toward an enlarging tail appears to have developed a little in advance of the first abundance of cephalopods, and as these animals probably fed on the trilobites, it is thought that the latter developed in defense not only a more rapid mode of swimming, but a backward one as well, a new locomotor addition to the abundant legs.

Size. — In size, the trilobites varied greatly at maturity, ranging in length from 0.38 of an inch up to 27.5 inches, but an average size was about 1.5 inches. Many species attained a length of from 3 to 4 and even 6 inches, but these were large individuals, and those above a foot in length were giants. Those represented as from 18 to 27.5 inches are, in nearly all cases, based on restorations pieced together from large fragments.

Geologic Duration. — Trilobites were characteristic of the Paleozoic era, beginning in considerable variety in the Lower Cambrian (about 37 genera and 125 species) and dominating the seas of the

Cambrian (about 95 + 625) and the Champlainian (more than 120 + 1050). In the Silurian, though they were still common, the trilobites were nevertheless on the decline (35 + 500), and this ebbing of their vital force is seemingly shown in many picturesque forms replete with protuberances, spines, and exaggeration of parts. As a rule, in evolution, one finds that when an organic stock is losing its vitality there arises in it an exaggeration of parts, as if heroic efforts were being made to maintain the race. Spinosity in animals is often the prophecy of tribal death. In the Devonian, the variety and number of the trilobites were greatly reduced (30 + 120), at a time when the ancient types of fishes, which undoubtedly fed on these crustaceans, began to be common in the seas. In the later Paleozoic seas, the trilobites were relics, or animals surviving from a time better suited to their needs, and one by one they vanished, until a little before the close of the Paleozoic era none were left. While they were in their prime, they dominated the life of the seas, since they were the chief carnivores and scavengers of Cambrian and Champlainian times, but with the rise of the cephalopods and the fish-like animals in the Silurian and the true fishes in the Devonian their death knell was sounded by the incoming greater mentality and alertness of these higher types.

Definition of Parts (study with Fig., p. 208).—The carapace of trilobites is divided transversely into (1) a head portion, called the *cephalon;* (2) a series of segments, forming the *thorax;* and (3) a tail-piece or *pygidium,* forming the abdomen. The *axis* is the area of the vital organs, while the *pleural regions* are protective coverings over the ventral limbs.

The cephalon or head is the most important part of the animal, and in the classification of the group has the most reliable features for ordinal and generic distinction. It is composed of a medial *glabella* and outer *free cheeks* bearing the *compound eyes.* In many forms the free cheeks are separated from the glabella by a *facial suture* which generally shows as a faint raised line, and in all such forms the three parts are apt to separate after death and thus cause imperfect fossils. In some trilobites compound eyes are not known, such forms being called blind; usually, however, two more or less large compound eyes are present. In the majority of trilobites each compound eye is covered over by a single cornea and the individual lenses beneath may or may not show through. In others each lens has its own cornea. The number of lenses in a compound eye may vary from fourteen to the astonishing number of fifteen thousand. Imagine an animal with thirty thousand eyes!

The thorax consists of a variable number of articulating segments (in the most primitive of all trilobites, *Naraoia*, there are none), the number being constant in the adults of each species, but variable in the young of each form and in the genera. With one exception there are never less than two, as in *Agnostus* (Pl., p. 201, Fig. 4), or more than forty-four. In a general way, it may be said that where there are many thoracic segments the pygidium is small, and where there are few the abdomen is large. It should be stated here that so long as these animals are growing, the new thoracic

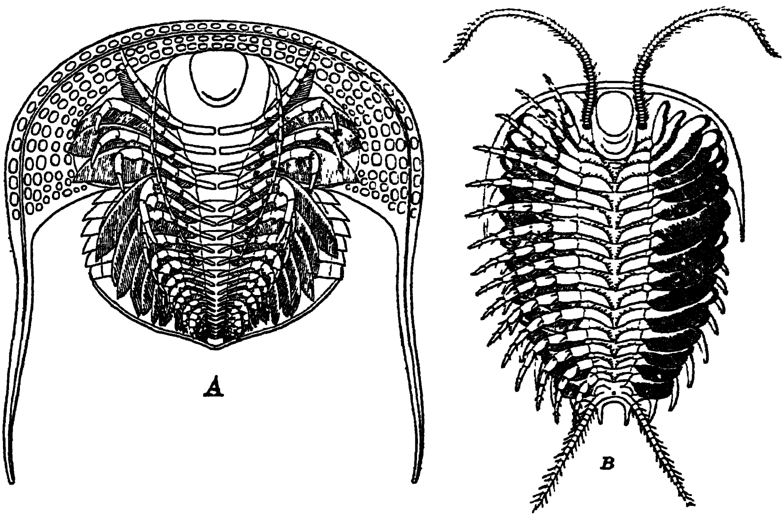

Fig. 65. — Restorations of the ventral side of two trilobites, to show the limbs, antennæ, and cercopods. Somewhat enlarged. *A*, *Cryptolithus tesselatus* Green, with the antennæ bent back (also see Fig. 13, p. 242); *B*, *Neolenus serratus* (Rominger), with the endopodites omitted on the right side, to show the exopodites better; note the two terminal cercopods. After Raymond.

segments added during the moulting stages are derived through the breaking down of the pygidium.

The pygidium or abdomen of trilobites may be small or large, and consists of a single piece of united segments varying between two and twenty-eight in number. Generally, the axial and pleural regions are plainly demarcated and some forms clearly show the number of coalesced segments.

Extending back from the pygidium in *Neolenus* are two *cercopods* that probably were used as sensory organs in the same way as the antennæ (Fig. *B*, above). These cercopods may have had their origin in the crawling legs. While the cercopods are known only

in this genus, it may well be that other small-tailed trilobites had them, but in large-tailed forms they were lost when the pygidium became a swimming organ.

Ventral Side. — Beneath the glabella and hinged to its bent-over and thickened posterior margin is the *hypostoma* or upper lip covering the mouth (Fig. *B*, p. 208). On each side of this plate there is a pair of short or long antennæ, many-jointed sensory or feeling organs. All the limbs are in pairs, and each limb is double, or biramous, with each of the two branches, in turn, made up of many joints.

The head has four pairs of such biramous limbs which serve also for chewing the food and passing it into the mouth. Back of the head each thoracic and abdominal segment has its similar pair of biramous limbs. Both limb branches arise from a single basal joint fastened to appendifers which are infoldings of the dorsal shell of the rachis. The stouter lower ramus or leg branch, with fewer joints, serves for crawling, while the other, which is more delicate and much more jointed, is used for swimming and is also replete with long hair-like appendages (setæ) that are delicate tubes in which the circulating blood extracts from the water the necessary oxygen for life sustenance (Fig. *D*, p. 208). Limbs are now known in twelve species and nine genera of trilobites, representing three orders and seven families.

Trilobite Moulting. — As trilobites grew, they periodically shed their chitinous shell, as do the crabs, and this happened many times before they attained full growth and probably occasionally during maturity. During the time of moulting, the animals grew and the detailed characteristics were changed, along with the introduction of new segments. These new segments were added just in front of the anal one, and at the time of moulting one or more of the forward segments of the pygidium may have been detached and added to the thorax. At first, the trilobite was a very minute, apparently unsegmented animal, all head (Pl., p. 242, Figs. 14, 15); then it consisted of head and pygidium, the latter of which rapidly added more segments; these stages were followed by other moults that long before maturity was attained rapidly introduced the full number of thoracic and pygidial segments according to the characteristics of each species. Later moultings simply enlarged the individuals.

Evolution. — Trilobites are the most primitive of Crustacea, and are generally assumed to have developed out of a many-segmented annelid in Proterozoic time. Recently, however, Raymond has postulated the progenitor of trilobites as having been a soft-bodied, depressed, floating-swimming, "worm"-like animal, composed of a few segments, probably with simple marginal eyes or even blind, with a mouth beneath the anterior margin, tactile organs at one or both ends, an oval shape, and a straight narrow gut running from the anterior mouth to the terminal anus.

It was probably the above type of animal that gave rise at some time during the Proterozoic to the trilobites, out of which then came some of the higher Crustacea. We may therefore say, with Raymond, that the trilobites gave rise, directly or indirectly, to all other arthropods.

For a complete discussion of the evolutionary trend among the Arthropoda the student is referred to Raymond's book.

TRILOBITES

Collateral Reading

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C. D. Walcott, Appendages of Trilobites. Smithsonian Miscellaneous
lections, Vol. 67, 1918, pp. 115–217.
C. D. Walcott, Notes on the Structure of *Neolenus*. Ibid., Vol. 67,
pp. 365–457.

CHAPTER XVII

BRACHIOPODA OR LAMP SHELLS

(See Pls. 7, 11, 21, 26)

All brachiopods have two shells, and the living forms are gregarious sexed animals that have their homes in the seas and oceans. More than 215 living kinds are known, extending from the strand-line down into the great oceanic abyss of more than 3 miles in depth. Their greatest abundance, however, is in the shallow water down to 1000 feet, where fully 80 per cent of the living forms occur, while 70 per cent live above 600 feet of depth.

At first these shelled animals were regarded as belonging to the bivalved molluscs to be described later, but Cuvier (1792 and 1802) was the first to see that this reference was wrong, although he still regarded them as of the phylum Mollusca. It was the Frenchman Duméril who in 1806 gave them the name Brachiopoda, which means *arm-footed*, because he thought these animals crawled around on their arms. Molluscs do crawl, but no brachiopod ever does, and therefore the name Brachiopoda continues a wrong physiological interpretation. What are called arms are really breathing organs, and it was these that Duméril mistook for the foot upon which the animals moved about (see Figs., pp. 216, 217). The individual brachiopods stay throughout life fixed to one place, the new-born young alone being free, and remaining unattached for some days or, rarely, two or three weeks.

Brachiopods are sometimes called *lamp shells* because many of the kinds living after Paleozoic time resembled a miniature Roman lamp. Most of the older brachiopod shells do not, however, in the least resemble these lamps.

External Structure. — Brachiopods have two valves (shells) which are situated on the ventral (belly) and dorsal (back) sides of the animals, and are hence known as the dorsal and the ventral valves (Fig., p. 215). In bivalved molluscs, on the contrary, the shells are on the right and left sides of the animal, and are therefore called the right and the left valves. Issuing from the ventral valve in the brachiopods there is a short, or in some types a very long, worm-like body known as the peduncle or pedicle (Fig. *A.*,

below). This is a fleshy stem, which in the great majority of cases anchors the animal to some foreign object on the sea bottom. It is only exceptionally that brachiopods in later life are without a peduncle and then the ventral valve is more or less cemented to some hard object, or otherwise held in place.

The shells of brachiopods are either phosphatic (phosphate of lime) or wholly calcareous (carbonate of lime). When phosphatic, they are usually thin and do not have ventral *teeth* and dorsal *dental sockets* or *hinge-lines* for the hinging or articulation of the valves (Figs. *A*, p. 216; *B* and *C*, p. 217) but are held together by muscles only; such forms are said to be *inarticulate*. All of the calcareous-shelled brachiopods are more or less well hinged and therefore *articu-*

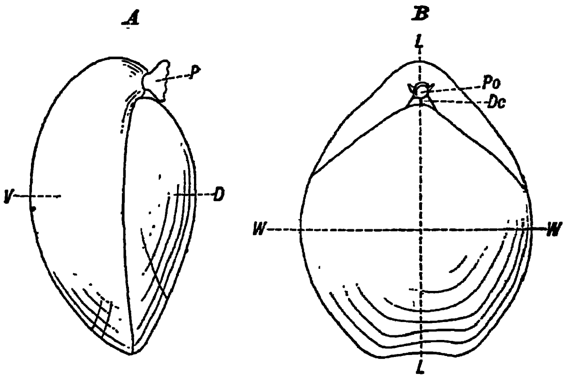

Fig. 66. — Diagrams of a lamp shell or brachiopod from the side (*A*) and dorsal view (*B*). *D*, dorsal valve; *Dc*, delthyrium, closed by two deltidial plates; *L*, length of shell; *P*, short pedicle by which the animal is permanently attached to foreign objects; *Po*, pedicle opening or foramen; *V*, ventral valve; *W*, width of shell.

late. The shell substance is said to be *impunctate* when there are no minute perforations passing through, and *punctate* when there are closely set canals in the valves. These cannot be seen with the naked eye, but with a pocket lens the canals in any punctate brachiopod are readily made out.

Internal Characters. — The shells are secreted by the *mantle*, which consists of two thin membranes that are not united marginally and have the form of the inside of the valves. They completely cover the soft parts of the animal, like skins, and their inner surfaces are respiratory.

On the inside of the two valves are usually seen *muscular impressions*, or markings on the places where the muscles were attached. These scars are different in the dorsal and ventral shells, and more

or less variable throughout this class of animals. Only the mos important and largest of them need, however, be mentioned. I: the ventral valve in the middle line are two small elongate scar called the *adductor impressions* (Figs. *A* and *C*, p. 217). These rep resent the places of attachment for the adductor muscles, o those which by contraction close the shell. The other ends of th adductors are seen in the four prominent scars of the dorsal valv (Fig. *B*, p. 217). On each side of the adductor impressions in th ventral valve are two large *diductor scars* (Figs. *A*, p. 216; *C*, p. 217) which open the shell and which pass backward to the posterio region of the dorsal valve and are there attached to a protuberanc known as the *cardinal process* (Figs. *A* and *B*, p. 217).

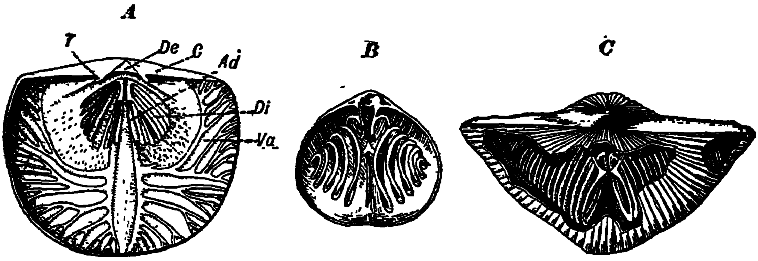

Fig. 67. — Internal characters of brachiopods. *A*, ventral valve of a strophomeni (*Rafinesquina expansa*). *B*, dorsal valve of a spire-bearer (*Nucleospira*), showin the skeleton that supports the arms. *C*, both valves with the dorsal shell broke to show the spiralia (*Spirifer striatus*). After Davidson. *Ad*, adductor scar: *C*, cardinal area, which also makes the hinge of the valves, and to which ar attached the teeth (*T*); *De*, open delthyrium where the pedicle emerged; *D* diductor muscle scars; *Va*, vascular markings.

Gills. — Within the anterior mantle cavity there are two more o less looped or spirally rolled, fleshy, fringed "arms." These ar the gills or breathing organs of the animals and the food gatherer as well. Through movements of the cirri and their cilia (the fring of the gills) they attract currents of water into the shell, where th microscopic food, chiefly plants (algæ), is extracted from it and fe to the mouth. Respiration takes place through the filaments of th gills, and through the inner surfaces of the mantle, which absorb th free oxygen taken in with the water.

In many brachiopods the gills are unsupported by internal cal careous skeletons, but in the majority there are such support and they are of much value in the classification of these lowly ani mals (see Figs., pp. 216, 217). The most primitive supports consis of two short, sickle-shaped hooks known as *crura*. When thes are more or less long and united in the middle, they are calle

ops (Fig. *B*, below), shells of this type being common after the Paleozoic; but when they bend outward into spiral coils, they are referred to as *spirals*, a type seen chiefly in the Paleozoic (Figs. *B* and *C*, p. 216).

Geologic Occurrence. — Brachiopods are particularly characteristic of Paleozoic time, and in North America about 2500 kinds are already known, while the known fossil forms of all countries and ages probably exceed 7000 in number. They appeared in some variety in the Lower Cambrian but it was in the Champlainian that

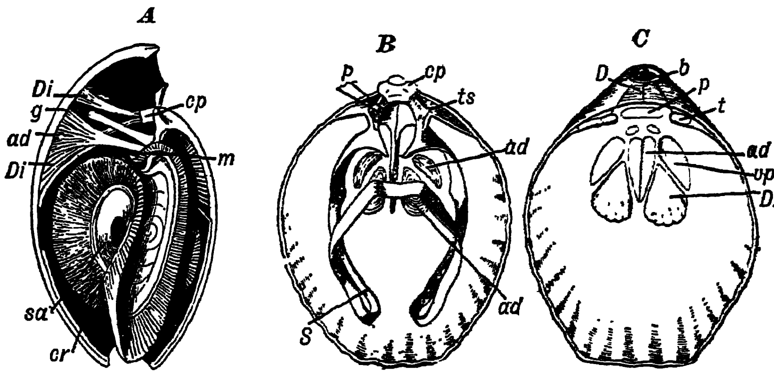

Fig. 68. — Internal structures of a loop-bearing brachiopod (*Magellania flavescens*). After Davidson, from Zittel's *Handbuch*. *A*, the shell and animal in section from the side. *B*, dorsal interior with loop or skeleton that supports the arms. *C*, ventral interior, showing muscle scars. *ad*, adductor muscles, two in ventral and four in dorsal valve; *b*, foramen through which pedicle emerges; *cp*, cardinal process to which are attached the ventral diductor muscles (*Di*); *cr*, cirri on edges of arms; *D*, two deltidial plates closing delthyrium; *Di*, diductor muscles that cross over to the cardinal process (*cp*); *g*, gut ending blindly; *m*, mouth area; *p*, place where pedicle is attached to shell; *S*, calcareous loop; *sa*, fleshy arms covering loop; *t*, teeth; *ts*, grooves into which articulate teeth of ventral valve; *vp*, ventral pedicle muscles.

they began their great specific and generic deployment and the class had its evolutional culmination in the Devonian, where 30 per cent of the American Paleozoic species occur. Then followed more or less of a decline throughout the Carboniferous and a marked vanishing of stocks during the Permian.

In the late Triassic a new evolution set in which attained its climax in the succeeding Jurassic. Here the shells known as *rhynchonellids* and *terebratulids* are most common and are the characteristic forms of the Mesozoic. Throughout this era the American continents are poor in brachiopods, probably fewer than 100 species being recorded, while in Europe the seas swarmed with them.

Brachiopods are of special importance as index fossils in Stratigraphy throughout the Paleozoic and Mesozoic. In the Cenozoic they have little importance, since they were then no longer a conspicuous clan, and probably at no time in this era were there more species than are living to-day. In North America less than 20 Cenozoic forms have been recovered.

Brachiopods are among the longest-lived animal stocks known, the genera *Lingula* and *Crania* having persisted through all the physical changes since the Cambrian.

It was said above that brachiopods appeared in some variety in the oldest Cambrian. Before the close of the Lower Cambrian three of the four orders into which the class is divided were in existence. This means that brachiopods originated in the Proterozoic.

Collateral Reading

JAMES HALL and JOHN M. CLARKE, Introduction to the Study of the Paleozoic Brachiopoda. Paleontology of New York, Vol. 8, 1892–1895.

CHAPTER XVIII

MOLLUSCA OR SHELLED ANIMALS

(See Pls. 9, 12, 22, 44)

Mollusca are often spoken of as shelled animals, though many of them are completely devoid of any external hard shell. Originally all of them had shells but throughout the geological ages many stocks abandoned the stiff outer armor so that they could the more easily move about. The Mollusca are a greatly diversified array of bilaterally symmetrical animals, and it is estimated that fully 45,000 kinds are now living. Such are the clams, oysters, snails, and the pearly nautilus. Their greatest diversification and abundance is in the seas and oceans. They are less varied and common in the fresh waters, while the air-breathing kinds of snails alone live on the dry land wherever there is vegetation.

The term Mollusca means *soft*, the bodies being very soft and devoid of an internal skeleton. They inhabit shells to protect themselves against their enemies. The bodies are not segmented as are those of the worms, and as a rule the animals are very sluggish. Though they are devoid of limbs for crawling or swimming, most of them do, however, move about, accomplishing this by means of the so-called *foot*, a creeping sole situated underneath the belly. Usually the body is covered by a *mantle*, a thin membrane that secretes the shell when such is present. Within the *mantle cavity* lie the *gills*, organs of varied construction setting up currents of water, out of which is extracted not only the oxygen for respiration but often also the food for life sustenance. In the land snails there are no gills and here the mantle cavity has been adapted into a kind of lung for aërial respiration, since they breathe the air. In all of the molluscs, except the bivalves, the mouth is furnished with a flexible chitinous ribbon known as the *radula*, a sort of tongue, usually provided with numerous minute, sharp, hard teeth and moved by special muscles for the breaking up of the food. The sexes are separate, or united, the individuals in the latter case being hermaphrodites.

Nature of Shell. — The shells usually consist of three layers: an outer, very thin, brown, *horny* layer always absent in the fos-

sils; a thick, middle, limy layer referred to as the *porcelanous* layer, the one most often preserved in the rocks; and an inner, generally thick, *mother-of-pearl* layer that is often destroyed in the fossils, especially among the Paleozoic molluscs, since it consists of an easily dissolvable form of carbonate of lime known as aragonite.

Classification of Mollusca. — The most primitive class of Mollusca are the *Lamellibranchia*, bivalves like the clams and oysters. They are primitive, however, only because they are degenerates, having in the course of their evolution lost their heads and eyes, due to their being completely encased between two heavy shells, which have made of them more or less sedentary animals. Originating in marine waters, they have spread into the fresh ones, but none have succeeded in living on the dry land.

The primal stock that gave rise to the Mollusca has not yet been found in the Proterozoic, but in the Cambrian the *Gastropoda* or snails are the common molluscs. From this and from the embryology of living forms it is evident that this clan in its construction is nearest to the primal molluscan stock. Throughout the geological ages the gastropods in their evolution are an ascending group of organisms and at present are more diversified than ever. They include the snails and drills.

Out of the gastropods came the highest and therefore the most complex and intelligent of molluscs, the *Cephalopoda*, such as the pearly nautilus, ammonites, squids, and devilfishes. The two first mentioned groups have shells and these are always abundantly chambered, while the squids and devilfishes have no shells at all, though there may be present something of an internal skeleton.

Significance of Molluscan Evolution. — The vast kingdom of the Mollusca started well, with bodily independence, fully equipped with locomotive powers, and with excellent innervation, but all excepting the cephalopods sold their birthright for ease and content. Even the cephalopods, with the marked degree of independence seen in the squids and devilfish, did not give rise to any stock higher than themselves. The gastropods, and especially the lamellibranchs, became dependent upon the movement of the water, and waited for the waves to bring them food. Secure in their protection and adaptation, these types of life have come crowding down the ages in inexpressible variety, but out of them can come nothing better. They had their chance at the very beginning of their ascendency, but the chance was missed, and for untold millions of years they have failed to improve. (J. M. Clarke, 1917. Also see his *Organic Dependence and Disease*, 1921.)

Lamellibranchia or Bivalves

The name Lamellibranchia comes from *lamella*, meaning *leaf*, and *branchia*, meaning *gills*, and was chosen because in these molluscs the gills are leaf-like. The class is also widely known as *Pelecypoda*, meaning *hatchet-foot*, because the foot often suggests the shape of a hatchet (Figs. *A*, below, and *A*, p. 222). The group includes all the headless and therefore *degenerate Mollusca*. The body is usually compressed from side to side and always covered with two shells or valves, one on the right, the other on the left side (Figs. *A* and *B*, below). They are therefore often called *bivalves*, and are popularly known as mussels, clams, oysters, cockles, and scallops. Their habitat is mostly marine, in the shallow waters near the shores, where their food, the microscopic algæ, is most abundant. Nearly all fresh waters, however, have some mussels, but none

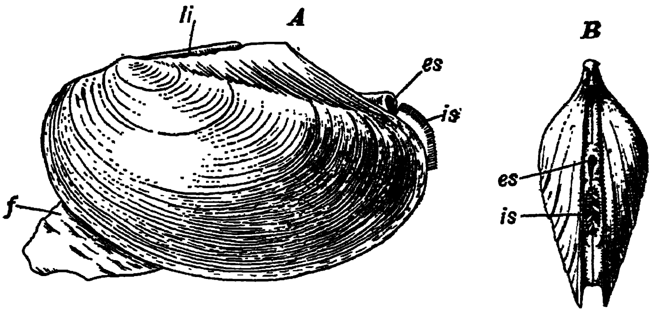

Fig. 69. — A fresh-water pearl shell (*Anodonta*). *A*, animal as seen from the left side. *B*, from the posterior end. After Howes. *es*, exhalant siphon; *f*, digging and crawling foot; *is*, inhalant siphon; *li*, ligament that opens valves.

have succeeded in living out of the water on the land, as do the snails. The food is strained out of the water by the gills (actually the labial palps), which are also the breathing organs. The lamellibranchs are very sluggish animals, many remaining buried in the sand and muds of the sea (Fig. *A*, p. 222). The scallops only can swim a little by clapping their valves and forcing water alternately from one side and then the other.

Shell Characters. — The two shells are joined on the dorsal side of the body by a *hinge*, a more or less thickened area provided with teeth and sockets, allowing the valves to move upon one another (Figs. *B* and *C*, p. 222). Either on the outside or within the thickened shell mass of the hinge area there is an *elastic ligament* attached to both valves that acts like a spring and keeps the shells open when the animals are in repose (Fig. *A*, above). On the inside of the valves

are muscle scars, usually one at each end of the shell, these being due to the *anterior* and *posterior adductor muscles,* though in many forms, as in the oysters, there is only one of these scars situated near the center of the valve (Figs. *B* and *C*, below). These muscles close the shell, and when it is shut the elastic ligament is under strain ready to open the valves again as soon as the adductors let go their pull. The wedge-shaped *foot* of the lamellibranchs is large in the creeping forms but more or less reduced in size through disuse, according

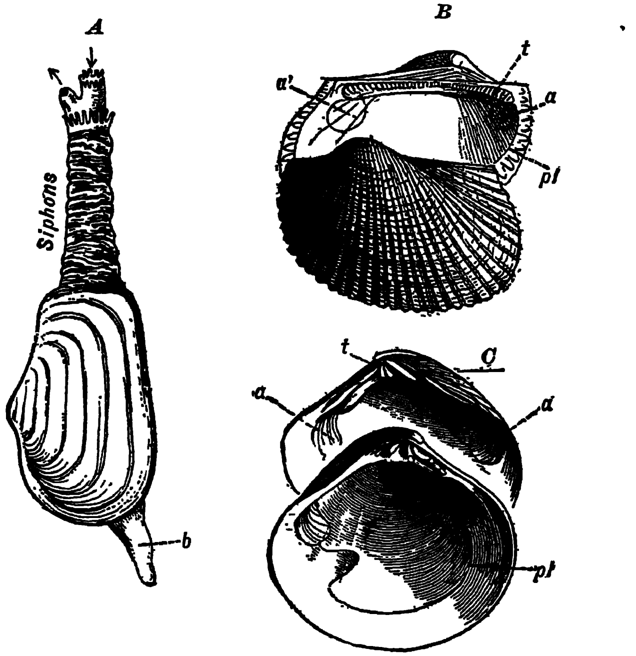

Fig. 70. — Marine bivalves. *A*, *Mya*, which lives buried in the mud. The long, partially retractile tube is the outer covering of the siphons. After B. B. Woodward. *B*, the two valves of *Arca* from the outside and inside. *C*, another type of bivalve (*Meretrix*). After Zittel's *Handbuch*. *a*, adductor or closing muscles; *pl*, pallial line where mantle is attached to shell; *t*, teeth of shell for articulation.

to whether the animals live in holes, like the soft clam, or have one shell firmly cemented to some hard object on the sea bottom, as in the oysters.

Contrasted with brachiopods, which also have two shells, it is seen that in that group the valves are on the dorsal and ventral sides of the animals, while in lamellibranchs they are on the right and left sides. The brachiopods have a complicated muscle system to open and close the shells, while lamellibranchs have such only

for closing them; they are opened by the elastic ligament. In brachiopods there is a peduncle that holds the animals to the ground, while bivalves are nearly always free to move about.

Siphons. — In most lamellibranchs the mantle elongates beyond the shell into two tubes or siphons through which the water of respiration enters and leaves the mantle cavity (Figs. *A*, p. 221, and *A*, p. 222). When the siphons are large, it is an adaptation for living buried in the sand or mud, and all lamellibranchs with such siphons have the shells marked on the inside by a decidedly bent line, the *pallial sinus*, seen in connection with the posterior adductor muscle.

Geologic Range. — Lamellibranchs were not well established until the Champlainian, after which time they became more and more abundant and are very prolific in all the shallow waters of the

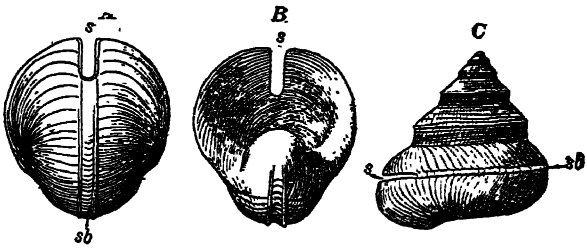

Fig. 71. — Two species of primitive marine gastropods. *A*, *B*, a form wound in a plane (*Bellerophon*). *C*, a form with a depressed spire (*Pleurotomaria*). After Zittel's *Handbuch*. *s*, slit or opening for siphons; *sb*, slit-band, the progressive track of the slit.

present oceans. While the shells of these bivalves are often abundant in the Paleozoic rocks, they are usually not well preserved until the Pennsylvanian, a condition seemingly connected with a rather thin porcelanous layer and a comparatively thick mother-of-pearl one, the latter being easily destroyed. They are only occasionally of value as stratigraphic markers in the Paleozoic, but, beginning with the Mesozoic, they are abundantly preserved and often serve as index fossils.

Gastropoda or Snails

General Characters. — The name Gastropoda means *stomach-footed*, and has reference to the fact that the animals creep about by contractions of the sole of the foot, which lies on the ventral side (Figs. *B* and *C*, p. 224). This class of molluscs, which are as a rule sluggish, though less so than the lamellibranchs, are exceedingly

varied and embrace not only such shelled forms as the limpets, drills, periwinkles, whelks, conchs, and snails, but also the naked sea slugs and the slugs of the land. They are most abundant and varied in the shallow seas, where they crawl over the bottom, are far less varied in fresh water, and on the land are represented by the vegetarian, air-breathing or pulmonate snails (so-called because the mantle cavity acts as a lung in respiration, see Fig. C, opposite), which are found in nearly all places where plants grow, and are very varied the world over. The mantle cavity in the aquatic forms usually has but a single gill, the one on the right side, that on the left side having been lost because of the spiral form of the body. In habit they are, as a rule, herbivorous, less often carnivorous and scavengers. The mouth is provided with a radula or tongue-like process. The carnivorous forms known as drills bore holes into their shelled victims, such as the clams, with the radula and the aid of a weak secretion of sulphuric acid. The head of most gastropods is usually distinctly marked off from the rest of the body, and has a pair of eyes and one or two pairs of sensory organs or tentacles (Figs. B and C, above).

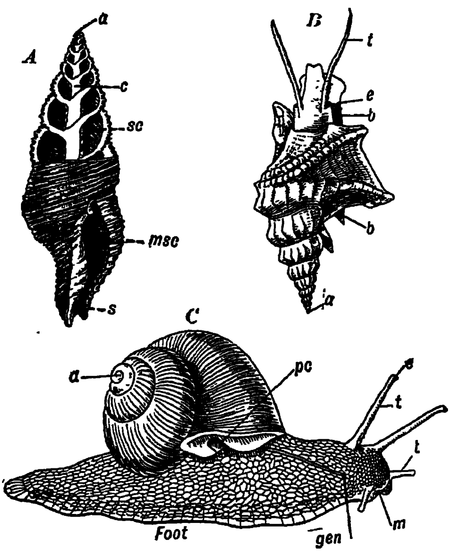

Fig. 72. — Gastropods. *A*, regular marine gastropod (*Latirus*), with the spiral shell wound to the right (dextral). After Steinmann. *B*, another marine gastropod (*Aporrhais*), with the animal crawling. After B. B. Woodward. *C*, an air-breathing (pulmonate) land snail in the act of crawling, the head with pairs of sensory tentacles, the long ones bearing eyes. After Hatschek and Cori. *a*, apex of shell; *b*, foot; *c*, interior columella; *e*, eye; *gen*, genital opening; *m*, mouth; *msc*, mouth of shell cavity; *pc*, opening into pulmonary cavity; *s*, siphonal cavity; *sc*, interior shell cavity; *t*, sensory tentacles.

Spiral Shell. — The usual form of the shell or protective covering is a spirally twisted, right-handed (dextral) cone with the apex directed upward (Fig. C, above); it is secreted by the mantle situated on the dorsal side of the animal. Because of this single shell, the gastropods are also spoken of as *univalve molluscs*. In many forms, however, there is a chitinous or calcareous *operculum*,

a plate attached to the side of the foot, which closes the shell opening when the animal has retreated into its shell or is retracted. Even though gastropods may thus have two shells, these together do not represent the two valves of bivalves. It is only the spiral cone that corresponds to the valves, because the operculum is a secondary structure not present in all univalves, is secreted by the foot, and has nothing to do with the dorsal mantle or true shell secretion.

Geologic Range. — Primitive forms of Gastropoda were present in the Lower Cambrian, where practically all of them were more or less conical, not twisted, but resembling little hoods. The twisted type of cone appears more and more abundantly in the Upper Cambrian and since the Champlainian has been common as fossils. At present there are living more than 20,000 species, a larger representation than at any time during the geologic past. In the Paleozoic they are, as a rule, defective fossils and it is only since the Mesozoic that their abundance in well preserved specimens is of value in Historical Geology. The air-breathing gastropods appear rarely in the Pennsylvanian and seem not to have been common until late in the Jurassic, where are also seen the first fresh-water snails. There are about 500 species of fossil pulmonate snails known and about 6000 kinds of land snails.

Cephalopoda

Cephalopoda (means *head-footed*) are the most highly organized Mollusca and include such animals as the nautilus, ammonites, octopus, cuttlefish, and squid. All are exclusively marine. The two former types of cephalopods have chambered shells in which the animals live, while the latter stocks are devoid of these. For present purposes the nautilids only will be described, because they are decidedly characteristic of the Paleozoic, and the remainder will be considered when Mesozoic animals are studied.

The living *pearly nautilus* (see Fig., p. 226) derives its name from the fact that its beautiful, bilaterally symmetrical shells are often used as ornaments and for pearl buttons, after the thin, outer, porcelanous, striped layer has been removed from the thicker, inner, mother-of-pearl one. The word nautilus is a poetic form of the Greek word for sailor, and like their distant relatives, the argonauts, it was believed that these animals could expand certain of their arms into the wind and so sail the seas. This idea, however, is wrong, for the four living species of the genus *Nautilus* now inhabiting Oceanica from the Malay region to the Philippine and Fiji islands have never been seen at the

surface except in a dying condition, though their empty sealed shells drift to Japan, Africa, and New South Wales. The nautilids are gregarious animals of the deeper and warmer sea between 300 and 600 feet, at a temperature of 68° F., but they have been taken in 1000 feet of water. In habit they are fierce and decidedly carnivorous and will take the meat that baits the fish-pots at depths down to 420 feet. The sexes are always distinct.

Cephalopods are also known as *chambered shells,* because the cone, of whatever form it may be, is regularly chambered by thin, pearly,

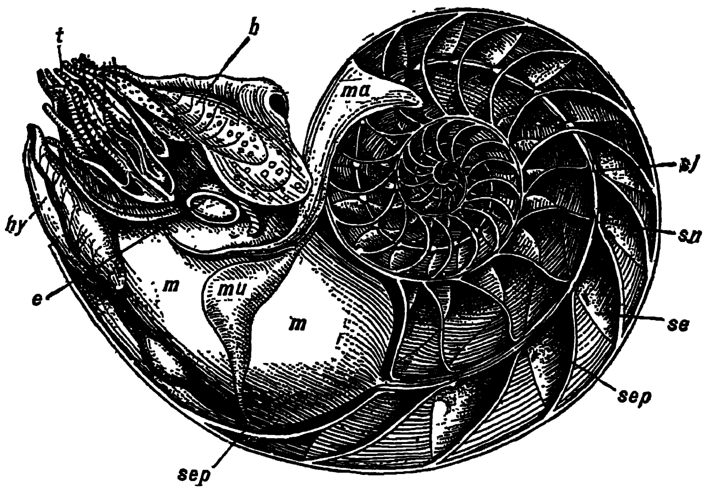

Fig. 73. — Pearly nautilus, with the shell cut through center to show internal chambers; the animal is fully expanded to show all of the external characters. × ½. After Hancock. *e,* large eye; *h,* hood or protective covering for the animal when retracted into the shell; *hy,* hyponome or funnel where water leaves mantle cavity; *m,* mantle, which encases animal and secretes shell (note prolongation into siphuncle); *ma,* dorsal prolongation of mantle; *mu,* muscle attaching animal to shell; *se,* chambers; *sep,* shell partitions or septa; *si,* siphon and siphuncle extending from animal through all the chambers to apex of shell; *t,* tentacles around mouth.

transverse partitions called *septa.* These septa are concave toward the opening of the shell, and are perforated by a circular hole. Through these perforations there passes a fleshy tube known as the *siphon* (Fig., above, *si*), originating on the rounded posterior side of the animal and continuing through all the chambers to the final minute one at the apex of the cone, where it is fastened to the inner side of the wall. In many fossil forms the siphon has secreted a calcareous tube, known as the *siphuncle,* which at times is very thick. In life the chambers are filled with a gas to make them more or less buoyant, and thus to render the weight of the stony house but little

of an encumbrance. The nautilids crawl over the bottom of the sea, or hold to it by their retractile tentacles, and can swim rapidly backward in a jerky manner by forcing out water from the mantle cavity through the *hyponome* or *ambulatory funnel.* To the sides of the cone the septa are firmly united, but in the fossils it commonly happens that the outer shell is lost, in which case the edges of the partitions show plainly as so many lines in the rock-filled cone. The nature of these lines is of much importance in classifying shell-bearing cephalopods, and they are termed *suture lines.* Usually these suture lines are straight, but there are forms in which they are decidedly bent in undulations. These, when convex toward the apex of the cone or backwardly directed, are termed *lobes,* and when curved toward the larger end or aperture of the shell, are called *saddles.*

Below the visceral sac is situated the large *mantle cavity* with its gill-plumes, where water is freely taken in and passed out through the funnel. When the animal wishes to swim, however, the two flaps of the mantle are appressed, forming the funnel, and by a rapid contraction of the mantle or gill chamber the inhaled water is shot out with great force. The animal then darts backward or sidewise according to the direction in which the stream is ejected. They are expert and rapid swimmers. The eyes on either side of the head are large, of primitive structure, and supported on short stalks called peduncles. The mouth is surrounded by the tentacles and is provided with two powerful, protrusible, horny, parrot-like bills, the upper one of which among fossil forms was often tipped with a carbonate of lime beak.

Geologic Occurrence. — Nautilids are the oldest and most primitive division of the Cephalopoda. They appeared with the Cambrian, were fairly abundant in the latest Cambrian, and increased in numbers in the Champlainian. The most primitive were straight, tapering cones that were circular or oval in outline, and the many families of them are called *Orthoceracones* (from the genus *Orthoceras,* meaning *straight horn,* Pl., p. 236, Fig. 19). These orthocerids were common throughout the Paleozoic and particularly so in the Champlainian and Silurian, when individuals are known that originally had a shell as long as 15 feet (*Endoceras*). With the Devonian these primitive straight-shelled forms began to wane slowly, but some were still present in the Triassic.

Straight and coiled nautilids persisted into the Mesozoic and were most abundant in the earlier half, after which time they gradually became less numerous. In the present oceans occur only the four relic forms, which give us our sole knowledge of the soft parts of the many thousands of kinds that swarmed the ancient seas.

Kinds of Nautilid Cones. — All the higher types of nautilids had their origin in the straight-shelled Orthoceracones. The first of the descendants had their shells slightly bent and are therefore called *Cyrtoceracones* (from *Cyrtoceras*, meaning *bent horn*, Pl., p. 236, Fig. 21); later ones were coiled in a loose spiral wound in a plane and are known as *Gyroceracones* (from *Gyroceras*, meaning *round horn*); still others are tightly wound, with the whorls embracing one another more or less closely, as in *Nautilus*, and these are termed *Nautilicones*. On the sides of such one sees more or less of the inner whorls of the shells, and the area of these whorls is spoken of as the *umbilicus*. It is small in *Nautilus* and wide or open in the Champlainian forms (Pl., p. 236, Figs. 23, 24). The bending of the tubes is due to a more rapid secretion of lime along the ventral side of the cone, and the greater the unequal growth the more rapidly the cone rolls up.

Classification. — Cephalopods are divided into two subclasses, the Tetrabranchiata and Dibranchiata, on the basis of the number of plume-like gills used to oxygenate the circulatory blood. In the former subclass there are four gills (*tetra*, four), and the latter division has but two. The Tetrabranchiata, all of which have external shells, appeared in the Cambrian, and have now almost vanished from the earth, while the Dibranchiata, which are in almost all cases naked but may have internal vestiges of the ancestral outer shell, arose in the Triassic and are abundantly represented among living cephalopods by the squids, argonauts, and octopus.

Habits of Fossil Nautilids. — In his studies of Paleozoic nautilids, Ruedemann states that from the nature of the preserved color bands it appears that among the forms with straight shells held horizontally, some crawled sluggishly forward over the bottom of the sea, or when in trouble darted backward quickly through the aid of the pumping siphon. Among the more active swimmers, the smaller and bent shells were held obliquely upward, and the coiled ones vertically. In the living nautilus the shell of the female has a somewhat different shape and larger size than that of the male, and this sex differentiation can be distinguished in some of the Paleozoic forms. The larger are regarded as the females and the smaller as males.

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CHAPTER XIX

CHAMPLAINIAN TIME AND THE REIGN OF INVERTEBRATE ANIMALS

General Characteristics of the Period

The Champlainian system of rocks lies above the Cambrian and beneath the Silurian, and the name is taken from Lake Champlain (New York-Vermont) where it is well developed. The time of Champlainian endurance was considerably longer than that of any of the six other Paleozoic periods, occupying in fact about one quarter of this era.

The Three Champlainian Floods. — North America during Champlainian time stood but little above sea-level, and it was only along the margins of the continent that there were uplands. For these reasons it was all the easier for the rising warm-water oceans to spread widely over the land. There were three cycles of floodings and withdrawals, of which the oldest one was of the least extent. The other two floods, mainly of Arctic waters, inundated North America very widely, in fact, more extensively than those of any other time. The second flood took place during the middle part of Middle Champlainian time (Trenton) and was followed by an almost complete withdrawal of these waters. Then early in Upper Champlainian time (middle Richmond) the Arctic waters returned to almost all the places of the earlier inundation.

Champlainian Sediments. — Early or Lower Champlainian time in America was one essentially of dolomite making, while during the middle epoch of this period thin-bedded limestones, along with shale formations, were the dominant kind of rocks laid down. Champlainian time in general may well be spoken of as one essentially of limestone making. During the last of the three epochs, thin-bedded limestones were also common, but accompanied by more muds (shales), and toward the close of the epoch came increasing amounts of sediments, with a prevalence of sandstones. These changes from the finest of sediments to coarse ones are evidence of rising lands, quickened erosion, and more rapid transportation of sediments by the rivers. The rising lands are those of Appalachis and especially Acadis, the area of the New England States and the

Maritime Provinces of eastern Canada. In western North America, Cascadis was the land from which the sediments in smaller amounts were delivered eastward into the Cordilleric trough.

St. Lawrence Seaways. — In the western portion of the New England States, and in southern Quebec (also New Brunswick), wherever Champlainian strata are known they are usually dark to black shales and greenish sandstones having but little limestone. These formations range in thickness from a few hundred up to more than 2000 feet, and contrast markedly with the dominant limestones and dolomites formed elsewhere during Champlainian time. Another interesting feature is the many thin and thick limestone conglomerates either at the base or in the lower portion of the Champlainian.

The St. Lawrencic sea was also an independent marine province and belonged to the Atlantic realm, since much of its life is common to western Europe. The region was, however, also more or less in connection with the Central Interior sea (see pp. 231, 238).

Interior Seaways. — In the interior of North America the Champlainian seas were, in the main, clear-water ones, depositing largely limestones. Toward the margins of these seas the sediment was greatly increased by the addition of much mud and some sands. In a broad, general way it may be said that there are in the middle Appalachian region from 6200 to 9700 feet of Champlainian strata, thinning down in the Mississippi valley to, at most, 1900 feet and in many places to less than 1000 feet.

Cordilleran Seaways. — In the Rocky Mountains region the greatest thicknesses are in Nevada and Utah, where there are Champlainian limestones, essentially Lower Champlainian ones, between 3000 and 5000 feet thick. These deposits thin down rapidly northward and also eastward, but in British Columbia they again thicken to the northward, for in the Mackenzie valley there appear to be more than 4000 feet of limestones, dolomites, and shales.

Champlainian Life. — With the two greatest marine transgressions came a profusion of life, and of all the floodings none brought a greater diversity of invertebrates than that of the Trenton. Fully 1200 species are known from the Cambrian of North America, but the Champlainian has four times as many. The period was, therefore, one of marvellously great evolutional progress among the lowly organisms. Of the land plants of this time, little has been recovered (Skiddaw of Wales and Maysville of Kentucky), and while fragments of peculiar armored fishes are abundant in Colorado, South Dakota, and Wyoming, they are not found elsewhere. Curiously, the

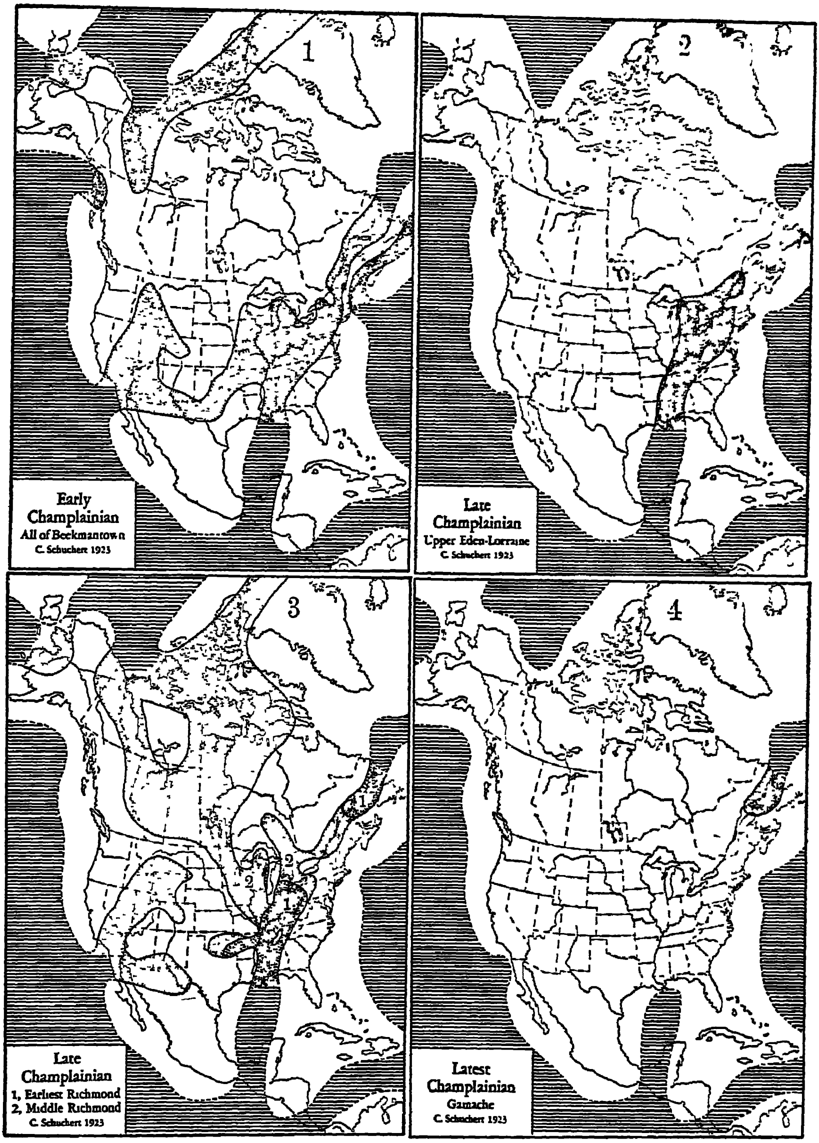

Plate 8. — Paleogeography of Champlainian time.

Epeiric seas dotted; oceans ruled. See Plate 10 (p. 238) for Middle Champlainian physiography.

Map 1 illustrates the first flood of this period; Plate 10 the second one; Map 3 shows the third flood, beginning in areas marked 1 and later becoming general; Map 4 brings out the widely emergent condition of North America toward the close of the Champlainian.

first appearance of fishes is in river deposits and this is of great significance in their probable evolution, as will be seen in the chapter on the origin of fishes. We may characterize the Champlainian as a continuance of the Cambrian marine invertebrate dominance, but with this difference, that in the younger period all the grander divisions and subdivisions of this type of animals are represented (see Pls. 9, 11, 12). Appearing for the first time in the Champlainian are the true corals, floating graptolites, crinids, bryozoans, and lamellibranchs.

Climate of Champlainian Time. — The vast limestone and dolomite accumulations of Champlainian time throughout North America, which have an abundance and great variety of life even in the Mackenzie valley and arctic Alaska, point to warm and equable waters. The same Middle Champlainian reef corals that are found in Tennessee and New York occur also in Baffin Land, the Mackenzie River valley, and Alaska, though they are less abundant in the far north. We may therefore assume that the temperature of the lands and the seas in the northern hemisphere was nearly everywhere the same, and that it was warm temperate throughout.

Many years ago Reusch discovered in arctic Norway (Finmarken) a series of tillites whose age could not be definitely determined, but which for general geologic reasons were thought to be of early Cambrian or late Proterozoic time. These tillites have recently been restudied by Holtedahl (1919), who finds that they occur in a sandstone series having a thickness of between 200 and 500 meters. The Bossekop-Mortensnes tillite has a thickness of about 10 meters, the Bigganjarga tillite of 2 to 3 meters. Their age can not even now be definitely fixed, but it is certain that they are either of Champlainian (Ordovician) or Silurian time. They appear to be the tills of local continental glaciers flowing northward.

Divisions of Champlainian Time

History of the Terms Champlainian and Ordovician. — It was Professor Lapworth of Birmingham University, England, who in 1879 proposed the term Ordovician, after the ancient tribe of Ordovices living in Wales at the time of the Roman Empire, to replace Murchison's Lower Silurian (1835). Further discussion of the term in connection with Cambrian and Silurian will be found in the chapters on those two periods. There is, however, a much older American term, Champlainian, which was proposed in 1842 by the geologists of the New York Survey. This is most appropriate for America, since in the region of Lake Champlain may be studied to good advantage most of the formations now embraced under Ordovician.

Basis for the Divisions. — Partly on the basis of the entombed fossils, but more particularly because of three distinct cycles of continental submergence, Champlainian time in North America is divisible into as many epochs of time, or series of strata. In each

epoch the oceans invaded more or less of the land and then withdrew from the continent, if not entirely at least in great part. These three epochs of the Champlainian are further divisible as follows:

TABLE OF CHAMPLAINIAN (ORDOVICIAN) FORMATIONS

		America		Europe
		Complete break with Silurian.		*Taconic emergence*
Upper Champlainian epoch		Gamache Richmond. Queenston-Juniata *Great spread of epeiric seas* Maysville-Lorraine Eden-Frankfort		Borkholm, Lyckholm of Esthonia. Horizon 5 and 4c of Norway. Trinucleus-Brachiopod shales of Sweden
		Vast but not complete retreat of sea.		*Mohawkian emergence*
Middle Champlainian epoch	Mohawkian	Cynthiana Collingwood Trenton-Galena-Bigby	Utica in wider sense	Jewe to Reval of Esthonia. Chasmops to Platyurus beds of Sweden. Most of 4 of Norway
		Amsterdam-Glens Falls Black River-Lowville-Leray		Caradoc, Bala, of Wales
		Great spreading of epeiric seas		
	Chazyan	Blount-Valcour Stones River-Crown Point-Day Point Big Buffalo-St. Peter		Llandeilo of Wales
		Complete break throughout North America.		*Lower Champlainian emergence*
Lower Champlainian epoch		Beekmantown-Quebec		Arenig-Skiddaw, Ceratopyge fauna
		Complete break with Cambrian		

Early or Lower Champlainian Epoch

In no place has there been determined an unbroken deposition from the Cambrian into the Lower Champlainian, and the submergences were restricted to the Acadian area, the eastern and central United States, and the Cordilleran region. Upward of 550 species are known from the Lower Champlainian, though if the strata were not so dominantly dolomitic, causing the destruction of the fossils, the total would probably be at least three times as great.

Life of the St. Lawrence Province. — The fossils of the St. Lawrence province are chiefly graptolites of the Atlantic realm, since very similar and even identical species recur in Great Britain, Sweden, and southern Norway. From Cape Breton, Matthew has described another variation of these Atlantic faunas (Ceratopyge fauna), and a similar facies with faunas of the same general type is also known in southeastern Newfoundland, where Van Ingen has described the Lower Champlainian in twenty-six zones.

Graptolites (from the Greek words meaning *written* and *stone*, so called because of their resemblance in the fossil state to ancient writings on stone) were colonial animals with chitinous external skeletons, the part that is preserved. They are related to living hydroids, the simplest of cœlenterates. There are two main kinds, the dendroids or bush-like forms that are anchored to the sea bottoms (Fig. *B*, below) and the free or floating kinds (Fig. *A*, below, and Figs. 1–6, p. 236). It is the latter that are of most significance in Stratigraphy, since they have widest distribution. Both stocks appeared early in the Champlainian and here the graptolites were most common, decreasing in number in the Silurian. In the Lower Devonian the free forms died out, and the dendroids in the Mississippian.

Quebec Conglomerates. — The thick limestone conglomerates in the Quebec series and at the base of the Champlainian system in Vermont are regarded by Sayles and Coleman as probably of glacial origin. The significance of these conglomerates has been discussed in the Cambrian chapter near its close.

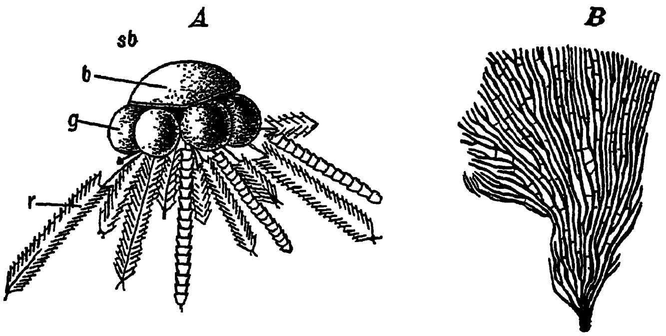

Fig. 74. — Graptolites or Paleozoic hydroids. *A*, restored colony of floating type (*Diplograptus pristis*). Somewhat enlarged. After Ruedemann. *b*, swimming bell; *g*, gonangia or brooding organs; *r*, a branch (rhabdosome) of many polyps in two ranges. *B*, dendroid type of anchored graptolites (*Dictyonema crassibasale*); the polyps are microscopic and like those in *A*. After Bassler.

Levis Shales. — The dark shale facies so characteristic of the St. Lawrence province occurs to the south of the St. Lawrence River all the way from near Gaspé, Quebec, to Levis, and thence southeast of Montreal, in Vermont on both sides of the Green Mountains, and in the Taconic Mountains in eastern New York to the south of Albany. These shales have many zones of graptolites, the lowest being marked by (1) *Dictyonema flabelliforme*, followed upward by (2) *Staurograptus*, (3) *Clonograptus-Tetragraptus*, (4) *Phyllograptus typus*, and zones of *Didymograptus* (see Pl., p. 236, Figs. 1–6).

The *Tetragraptus-Phyllograptus* faunas made up of floating forms are world-wide in their distribution. First made known from Canada by James Hall between 1858 and 1865, they have since been reported in many places in the United States, Scandinavia, Wales, Belgium, France, Peru, Bolivia, Australia, and southern New Zealand. Among the graptolites we often see cosmopolitan and widely distributed assemblages, due to their floating habits.

Life of the Appalachian Province. — From northern Lake Champlain south, and more especially from central Pennsylvania into

Alabama, there is a series of heavy-bedded dolomites that have a totally different series of fossils from those of the St. Lawrence province. These strata are also known in much thinned formations in western Tennessee, the Ozark region of Missouri, and in the upper Mississippi valley. In most places the dolomites are marked near their base by growths of lime-secreting algæ known as *Cryptozoön* (Fig., p. 198), and at many horizons by peculiar intraformational conglomerates, the pebbles of which are usually of thin, flat pieces, the washed-together broken débris of sun-cracked magnesian limestones. Other than the algæ, these dolomites are poor in fossils, due to the alteration from limestones they have undergone during deposition, though in favored places Mollusca still abound, chiefly thick-shelled gastropods and their curious horn-like and more or less long opercula known as *Ceratopea;* also a variety of straight, bent, and coiled cephalopods (see Pl., p. 236, Figs. 16–24).

In western Newfoundland there is another representation of this same province in dolomites and magnesian limestones more than 2000 feet thick. Across the Atlantic it is again present at the north end of Scotland in the Durness limestone, and Holtedahl reports it on Bear Island south of Spitzbergen and in extreme northern Norway in Finmarken.

Life of the Cordilleran Province. — The Lower Champlainian is also known to be present in thick formations in the Cordilleric trough, and here the faunal development is again different from that of either the St. Lawrence or the Appalachian area, though dolomites and magnesian limestones are the dominant rock types in both.

Lower Champlainian Emergence. — In all the known areas of North America west of Appalachis and Acadis, there is a marked change in sedimentation between the Lower Champlainian and the succeeding strata of Middle Champlainian time. The older formations are dolomites, while the younger ones are thin-bedded limestones. Furthermore, the Middle Champlainian seas transgressed more widely and their faunas were totally different from those of the earlier epoch. This change is a striking illustration of the fact that the apparently insignificant break — the contact is everywhere a disconformable one — between the Lower and Middle Champlainian is of much time import in that the greatly altered faunas have undergone a long evolutional change. In other words, the break in deposition represents a loss of record long enough for the earlier faunas to have evolved into those so characteristic of Middle Champlainian time. This change is seen best in a completely different series of graptolites; a far greater prevalence of brachiopods, molluscs, and

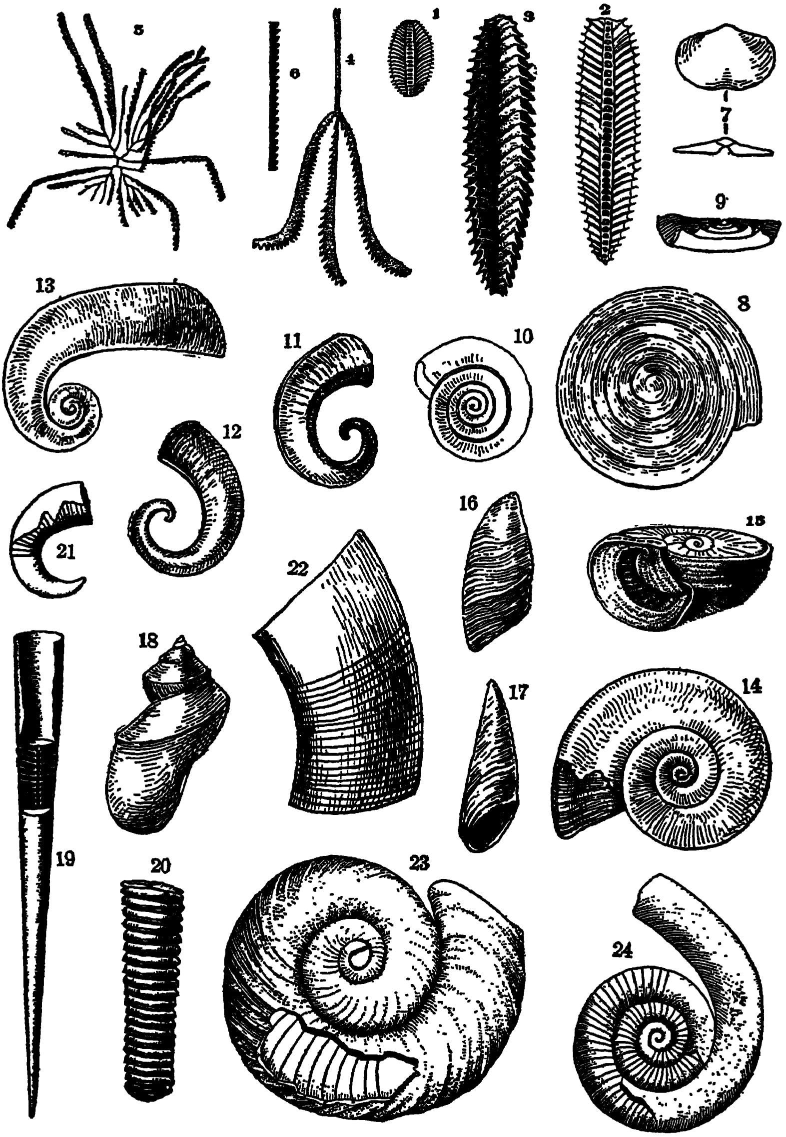

Plate 9. — Mainly Lower Champlainian fossils: graptolites (1–6), brachiopod (7), gastropods (8–18), cephalopods (19–24).

Figs. 1, 2, *Phyllograptus ilicifolius* and *P. angustifolius*, crushed flat; 3, *P. angustifolius*, uncrushed, × 2; 4, *Tetragraptus fruticosus;* 5, *Goniograptus postremus*, × $\frac{1}{2}$; 6, fragment of *Loganograptus logani;* 7, *Syntrophia lateralis*, × 2; 8, *Ophileta complanata;* 9, 10, *O. compacta;* 11, 12, *Eccyliopterus triangulus*, × $\frac{2}{3}$; 13, *Orthostoma lituiformis*, × $\frac{1}{2}$; 14, *Maclurites acuminatus;* 15, *M. logani* of higher strata, to show the operculum in place; 16, 17, *Ceratopea keithi*, the operculum of an unknown *Maclurites;* 18, *Eotomaria* (?) *cassina*, × $\frac{1}{2}$; 19, *Orthoceras multicameratum* of the Middle Champlainian, × $\frac{1}{10}$; 20, *Protocycloceras whitfieldi*, × $\frac{1}{2}$; 21, *Cyrtoceras juvenale* of the Middle Champlainian, × $\frac{1}{2}$; 22, *Ooceras kirbyi;* 23, *Plectoceras* (?) *occidentale* of the Middle Champlainian, × $\frac{1}{4}$; 24, *Schroederoceras eatoni*, × $\frac{1}{3}$.

In the main after the New York State Survey, R. P. Whitfield, and H. F. Cleland.

ostracods; the first crinids and fishes; and for the first time an abundance of bryozoans.

Ozark Dome. — In southern Missouri and northern Arkansas are exposed ancient granites, around which are arranged in crescents and rings the early Paleozoic formations. This arrangement, and particularly the thinning out of many of the formations by overlap against the granites, indicates dome structure, a periodically rising area in the midst of shallow depression fields having epeiric seas. This dome appeared probably toward the close of the Cambrian.

Wisconsin Uplift. — In northern Wisconsin is exposed an ancient mass of rocks, a southern prolongation of the Canadian Shield or Laurentis. Around this peninsula-like mass in the east, south, and west are arranged in an irregularly parallel way the early Paleozoic formations. This headland came into existence seemingly with the Killarney mountains toward the close of the Proterozoic.

Middle Champlainian Epoch

Seas. — The Middle Champlainian was a long epoch and one with much change between land and sea. The seas were oscillatory and variable, with a final great inundation from the Arctic, the first of a series of Paleozoic floods from this ocean. The maximum submergence occurred early in Trenton time, when the Arctic flood had its greatest extent and seemingly covered about one half of the continent. More of North America was then beneath the sea than at any other time since the beginning of the Paleozoic. Our knowledge of the Cordilleric sea of this time is not extensive, but there appears to have been a through waterway from the Great Basin country into the Arctic Ocean. Encroachments by the Atlantic Ocean were restricted to the northeast of the continent and this ocean sent but little of its life into the Central Interior sea. Finally, nearly all of the marine water was withdrawn, completing the ebb and flow of Middle Champlainian time. (See Pl., p. 231.)

Life. — During no one of the Paleozoic inundations did the life of the sea record itself so completely by its fossils in the sediments as during the Middle Champlainian epoch. The waters swarmed with a vast variety of invertebrate animals, and there are known from North America alone more than 2600 species, chiefly of bryozoans (exceedingly small animals, remotely resembling corals), brachiopods, gastropods, cephalopods, and trilobites (see Pls., pp. 240, 242). There are about 500 kinds of brachiopods from these deposits in North America, and when the bryozoans are all described there will be more than 1000 species of them. The contribution of the latter as limestone makers, notwithstanding their minute size, Ulrich believes to have been twice as great as that of the brachiopods. There appear to have been as many kinds of gastropods as of brachiopods.

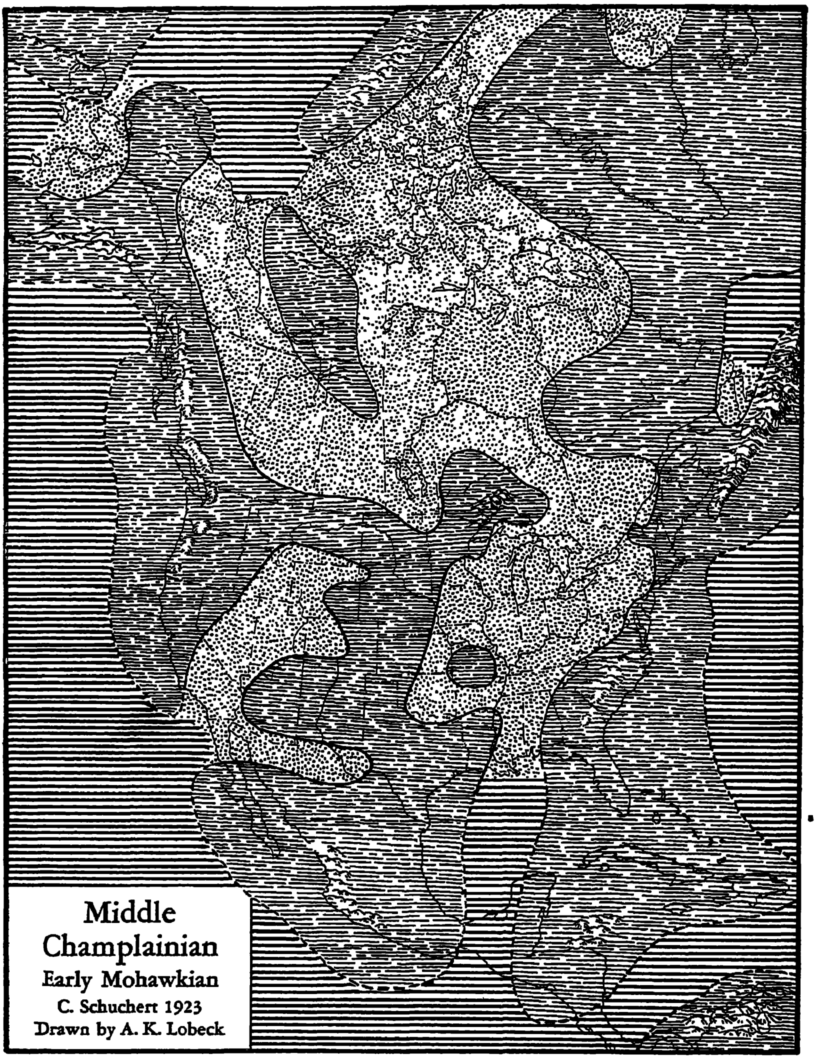

Plate 10. — Middle Champlainian paleophysiography

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 8 (p. 231) for Champlainian paleogeography.

The probable geography of Middle Champlainian time, when the lands were widely peneplained and the seas depositing limestone in the main. The seas are described on page 237. The drainage is unknown.

On the lands there may have been some vegetation, and the climate was warm and moist.

Trilobites are often common and well preserved and include more than 300 kinds, but in general they are neither large nor ornate (see Pl., p. 242). The sponges are conspicuous by their rarity. Crinids (animals related to the star-fishes but fastened to the ground by a stalk, see Pl., p. 240, Fig. 5) are locally common, and contributed largely to the making of limestones. The first true Paleozoic corals appeared here, both cup (Pl., p. 240, Figs. 3, 4) and compound forms, along with stony hydroids (stromatoporids), and exhibited a tendency to form reefs.

First Vertebrates. — In 1891 Walcott announced the finding of an abundance of fragmentary vertebrate remains in the Champlainian near Canyon City, Colorado, and since then similar remains have been found in the Big Horn Mountains of Wyoming and the Black Hills of South Dakota. These fossils usually occur in a sandstone 6 to 8 feet thick at the base of the Middle Champlainian deposits of the Cordilleric sea. There can be no question that these are the armor bones of fishes of the same type seen often in late Silurian and throughout Devonian time (Ostracoderms). They are described in Chapter XXIII. From their fragmental nature and their occurrence in sandstones it seems probable that these fishes were inhabitants of fresh waters, and that after death they were drifted by the rivers and broken up before arriving in the marine sediments of the littoral.

Nelson's Volcano. — At about the time when the Arctic waters were spreading most widely across North America, there stood a volcano somewhere in eastern Kentucky (between Fayette and Elliot counties). In 1921, W. A. Nelson directed attention to an ash bed in the Lowville formation covering an area of about 360,000 square miles in the Southern States, and of a thickness ranging up to 7 feet. He estimates that the amount of ash blown out equals 66 cubic miles. Until this ash bed (a bentonite or decomposed rhyolitic ash) was discovered, no one had suspected the presence of a volcano anywhere in eastern North America in Champlainian time.

Mohawkian Emergence. — After the great flood in early Trenton time, the waters began to retreat into the oceanic basins, first from the medial portions of the continent and finally from the northern ones. Some water appears to have remained in the southern portion of the Central Interior sea, completing here the marine record between Middle and Upper Champlainian times. It is this vast retreat of the Middle Champlainian epeiric seas and the succeeding long and more or less emergent time of the early Upper Champlainian that bring about a natural separation of these formations into two series of strata (see Pl., p. 231)

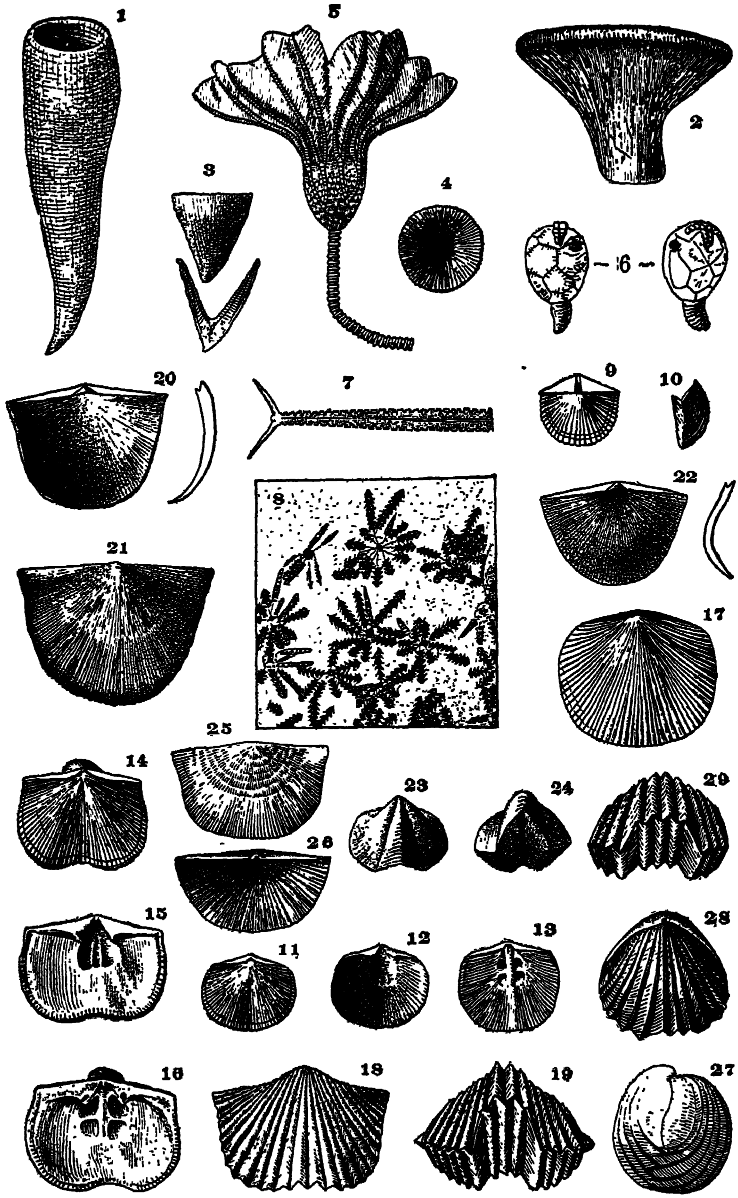

Plate 11. — Middle and Upper Champlainian sponges (1, 2), corals (3, 4), crinid (5), cystid (6), graptolites (7, 8), and brachiopods (9–29).

Fig. 1, *Cyathospongia reticulata*, $\times \frac{1}{2}$; 2, *Zittelella typicalis*, $\times \frac{1}{2}$; 3, 4, *Streptelasma profundum*, $\times \frac{1}{2}$; 5, *Glyptocrinus dyeri*, $\times \frac{1}{3}$; 6, *Lepadocrinus moorei;* 7, *Climacograptus bicornis;* 8, *Diplograptus ruedemanni*, $\times \frac{3}{4}$; 9, 10, *Orthis tricenaria*, $\times \frac{3}{4}$; 11–13, *Dalmanella testudinaria;* 14–16, *Hebertella sinuata*, $\times \frac{1}{2}$; 17, *Dinorthis subquadrata*, $\times \frac{3}{4}$; 18, 19, *Platystrophia laticosta*, $\times \frac{3}{4}$; 20, 21, *Rafinesquina alternata*, $\times \frac{3}{4}$; 22, *Strophomena planumbona*, $\times \frac{1}{2}$; 23, 24, *Triplecia extans*, $\times \frac{1}{2}$; 25, *Leptæna rhomboidalis*, $\times \frac{3}{4}$; *Plectambonites sericeus;* 27–29, *Rhynchotrema capax*, $\times \frac{3}{4}$.

In the main from the New York, Ohio, and Indiana State Surveys.

Upper Champlainian Epoch

Seas. — The formations of this epoch were first studied in southwestern Ohio and chiefly about Cincinnati, and to the rocks in this region the name *Cincinnatian* was applied by Meek and Worthen in 1865. The Middle Champlainian sea had almost completely vanished from the continent when a new cycle of water movement spread from the Gulf of Mexico northeastward along the western side of Appalachis, northward into the Ottawa basin, and westward into Indiana. This was the sea of Eden and Maysville time (see Pl., p. 231, Map 2), a muddier water than that of the two earlier invasions, and it brought back to the interior sea the previous southern faunas that had been changing elsewhere during the emergent interval into other forms. After nearly 500 feet of shales and thin-bedded limestones had been deposited, another flood from the Arctic Ocean arrived, spread its Richmond fauna far and wide over North America and submerged more than 40 per cent of the continent (see Pl., p. 231, Map 3).

Queenston Delta. — While this flood was at its greatest, there formed in the medial Appalachic trough a very large river delta of red sandstones (Juniata), extending from Maryland north into New York, where the brick-red sandy muds may be seen at Niagara Falls (Queenston).

Life. — The Upper Champlainian faunas were at first very similar to those of the previous epoch, but the subsequent Atlantic and Arctic invasions introduced new types of animals which gradually changed into others prophetic of Silurian time. These differences are seen more especially among the bryozoans, brachiopods, and reef-building corals. However, there is still so marked a Middle Champlainian stage of organic development present in the faunas of the Upper Champlainian series as to compel its closer association with the Champlainian than with the Silurian.

Cincinnati Axis. — The Cincinnati axis or geanticline is a broad and depressed arch in the Paleozoic strata of the eastern part of the Interior Lowlands. It is seen at the surface extending from north of Cincinnati south to beyond Nashville (see Fig., p. 141). To the east of the arch is the Ohio basin and to the west of it the Indiana basin. This arch began to form in Middle and Upper Champlainian time, but was not a separating ridge in the Great Interior sea until after early Silurian time. In Middle Silurian time a part of the arch in central Kentucky sank below sea-level and this depression was renewed from time to time and harbored marine waters as late as the Pennsylvanian. On the other hand, the southern and

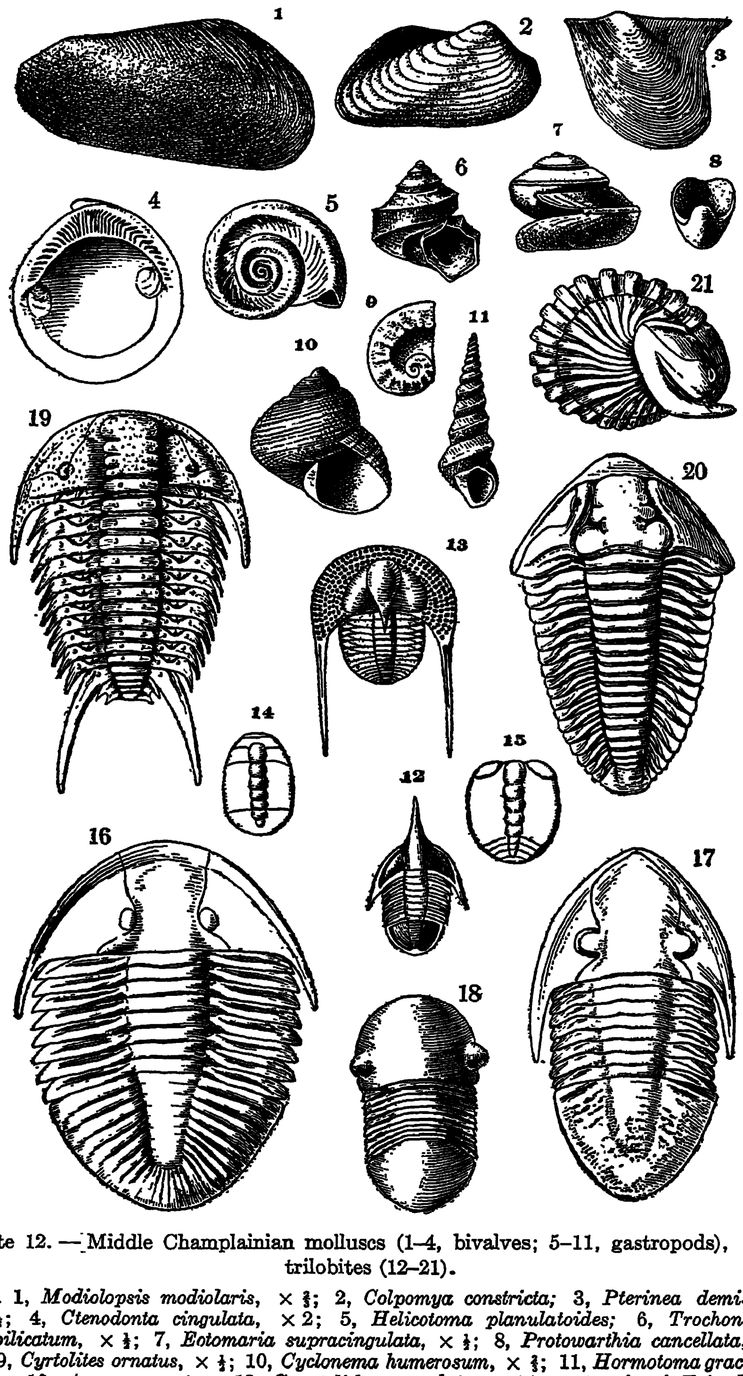

Plate 12. — Middle Champlainian molluscs (1–4, bivalves; 5–11, gastropods), and trilobites (12–21).

Fig. 1, *Modiolopsis modiolaris*, $\times \frac{2}{3}$; 2, *Colpomya constricta;* 3, *Pterinea demissa*, $\times \frac{1}{2}$; 4, *Ctenodonta cingulata*, $\times 2$; 5, *Helicotoma planulatoides;* 6, *Trochonema umbilicatum*, $\times \frac{1}{2}$; 7, *Eotomaria supracingulata*, $\times \frac{1}{2}$; 8, *Protowarthia cancellata*, $\times \frac{1}{2}$; 9, *Cyrtolites ornatus*, $\times \frac{1}{2}$; 10, *Cyclonema humerosum*, $\times \frac{2}{3}$; 11, *Hormotoma gracilis*, $\times \frac{1}{2}$; 12, *Ampyx nasutus;* 13, *Cryptolithus tesselatus;* 14, protaspis of *Triarthrus becki*, $\times 20$; 15, same of *Proëtus parviusculus*, $\times 20$; 16, *Ogygites canadensis*, $\times \frac{2}{3}$; 17, *Isotelus iowensis*, $\times \frac{1}{2}$; 18, *Bumastus trentonensis*, $\times \frac{1}{2}$; 19, *Ceraurus dentatus;* **20, 21,** *Calymene meeki.* (242)

especially the northern end was widely invaded at different times by the Great Interior sea. Finally, the top of the entire arch was completely truncated by aërial erosion, since the Upper Devonian sea spread its black muds across both the Nashville and Cincinnati domes.

Taconic Emergence or Disturbance

Evidence. — From a study of the paleogeography of Middle and Upper Champlainian time, it is seen that the seas were undergoing much change. This unrest in the hydrosphere was apparently due to movements within the bordering masses of the North American continent, not only depressing and elevating the land but affecting the general level of the strand-line as well. We have seen that the greatest mass of sediments was laid down along the inner margins of Acadis and Appalachis, and here in the geosyncline, therefore, occurred the greatest depressions of the original land surfaces. In eastern Pennsylvania this maximum sinking was over 15,000 feet during Cambrian and Champlainian time, and it was about the same, or even 1500 feet greater, along the eastern side of Lake Champlain. In the Great Basin area of the Cordilleric sea the sinking of the bottom during the Early Paleozoic was also great, being over 16,000 feet.

Metamorphism. — In Vermont, and throughout the Taconic Mountains, the Cambrian and Champlainian sandstones are now quartzites, the shales are slates, and the limestones are marbles. This regional metamorphism took place largely if not wholly when the strata were folded and thrusted to the west during the Appalachian Revolution (p. 426) and not, as has been thought, at the close of the Cambrian or the Champlainian. Some of the metamorphism, however, may have been connected with the Acadian disturbance of late Devonian time (see p. 316), along with the injection of igneous rocks now seen to best advantage in the White Mountains of New Hampshire.

It is clear that there was a wide-spread elevation of the New England-Acadian area (= New Brunswick geanticline), beginning before Richmond time, and seemingly renewed at the close of the Champlainian. This elevation is known to have been of a folding or orogenic nature only over a small western part of the area mentioned, and to have renewed erosion in a marked manner. The deposits of this wear and tear of the land are seen in the wide-spread, red and thick delta deposits of the Upper Champlainian series (Juniata and Queenston formations), and in the thicker and more extended ones of the succeeding Silurian (Medina). Together these coarse deposits made up the *Queenston delta.*

The relief of internal stresses is known to have folded the pre-Silurian strata from at least Port Jervis, New York (see Fig., p. 263), northeastward to Kingston and Hudson (Becraft Mountain). Curiously, however, the often recited evidence for folding at this time, said to have been general throughout the New England States and the Maritime Provinces of Canada, fails to be borne out by the more recent geologic work in these areas. This work does not, however, demonstrate that there was no Taconic folding or mountain making. H. D. Rogers in 1837 was the first to note the significance of the marked angular unconformity at Kingston and described it at length in his famous *Geology of Pennsylvania*, published in 1859. Considering this evidence and the apparently similar unconformity at Gaspé, Quebec, Dana was led in 1874 to postulate a general upheaval and the making of mountains throughout the area mentioned above. More recently J. M. Clarke has restudied the geology of Gaspé and concludes that the unconformity is due to overthrusting. Therefore all of the confirmed evidence of mountain making is restricted to a narrow and not long area in the state of New York. For the present, then, the Taconic disturbance must rest upon what is known, but the chances are good that a wider field of orogeny will be proved along the western side of the New Brunswick geanticline. The whole evidence for the Taconic disturbance as recorded in the literature has recently been reviewed at length by T. H. Clark (1921).

Orogeny in Europe. — In Great Britain there was important mountain making toward the close of the Ordovician. It was most marked in western England, Wales, and Ireland, where the Silurian rests unconformably upon the older metamorphosed strata. Then, too, in Great Britain, all through Middle and Upper Ordovician time, ashes and lavas, along with intruded deep-seated plutonic rocks, were added to the coarse marine sediments. Jukes-Browne holds that this orogenic movement extended, but with less intensity, far into northern Norway.

The only other extensive mountain ranges known to the writer to have been made in Ordovician times are those of eastern Australia, and this folding was accompanied by much volcanic activity.

Economic Products of the Champlainian

Trenton Oil and Gas. — Between 1886 and 1900, Ohio and Indiana were yielding vast quantities of petroleum and natural gas. To-day the yield in these states is small. It came from the upper 20 to 30 feet of the Trenton dolomite, in places where it is highly crystalline, and at depths of from 1100 to 2200 feet below ground (Fig., p. 257). The Middle Champlainian strata of Illinois are now yielding petroleum in commercial quantities.

The Trenton oil and gas fields are connected in the main with the "terrace structure" of the Cincinnati uplift and are situated under its northern end, and under the short northeasterly trending arch known as the Lima spur of Ohio and the broader northwesterly trending arch known as the Wabash spur of Indiana. The once famous Karg gas well of Findlay, Ohio, stood on the edge of a rapid descent of the Trenton dolomite; and only a thousand feet west

of it, where the top of this formation lay 120 feet lower, the adjacent well yielded petroleum.

Slate. — In the Appalachian region, and especially in Pennsylvania and Vermont, Lower Cambrian and Champlainian slate belts are much quarried for black, green and blue, purple and red slates. The uses of roofing and "mill-stock" slate are now very varied, and the annual production is valued at over $4,000,000. Nothing is more astonishing to see than the vast waste piles of a slate quarry, the worthless material including from 60 to 80 per cent of the rock quarried.

Limestone, Marble, and Cement. — Because of the wide surficial distribution of the Champlainian limestones, they are much quarried for foundation structures, road metal, flux for the reduction of iron ores, and especially for the lime used in mortar, whitewash, and fertilizer for farm land. The annual value of this raw material now ranges around $55,000,000; manufactured, the value is ever so much greater. In the Appalachian valley of Virginia and Pennsylvania they are also much used in the making of Portland cement. In Vermont there are immense quarries in the Middle Champlainian from which is obtained most of the American Carrara, or white and clouded marble. In eastern Tennessee some of the Middle Champlainian fossiliferous limestone is mottled pinkish to deep red in color and is used for decorative and interior building. The annual value of these marbles is now about $5,000,000.

Lead and zinc, mainly in the form of sulphides and carbonates, have been mined for more than a century and in considerable quantity from the Middle Champlainian dolomites of eastern Iowa, southern Wisconsin, and northern Illinois; the formation from which they come is known to geologists as the Galena formation, and is of the same age as the Trenton of New York. The ores occur in solution cavities, in crevices, or as replacements of the limestone and they were leached out of the higher strata by the aërial waters percolating through them, and then segregated at lower levels in the places now found. They were redeposited, however, long after Champlainian time. Some lead is also yielded by the Upper Cambrian of the Ozark region of Missouri and Arkansas.

Iron Ore. — In southeastern Newfoundland there are rich oölitic iron-ores of early Champlainian time, occurring in five zones.

Calcium phosphate, valuable as a fertilizer, is obtained in central Tennessee, where the Middle Champlainian limestones are rich in tiny gastropods (*Cyclora*) having phosphate of lime shells.

Collateral Reading

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E. R. CUMINGS, The Stratigraphy and Paleontology of the Cincinnati Series of Indiana. 32d Annual Report, Indiana Department of Geology and Natural Resources, 1907, pp. 607–1188.

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CHAPTER XX

PETROLEUM AND NATURAL GAS, THEIR DISTRIBUTION AND ORIGIN

In this chapter we are to study two of the greatest sources of natural wealth, mineral oils or petroleum (rock oil), and natural gas. Their annual value is now next to that of coal and iron, so that their exploitation has led to vast personal fortunes, greater than that of Crœsus; and through their benefactions some of the owners of this great wealth are stimulating the world to nobler and healthier living. The "master mind" of the petroleum industry is John D. Rockefeller of New York.

Manifestations of natural gases and oils issuing out of the ground in the form of "burning springs," iridescent films on the surface of streams, or lakes of asphalt, are nothing new, for such phenomena of nature have been recorded in human history these thousands of years. "The vale of Siddim was full of slime pits," we read in Genesis XIV: 10. "Slime had they for mortar" (Gen. XI: 3) in the building of the tower of Babel. Herodotus also tells that the bricks and tiles of the temples of Babylon, "the brick city," and Nineveh, "the stone city," were held together by pitch or asphalt, and the latter city paved its streets with asphalt more than 4000 years ago.

Rise of Petroleum Mining. — The earliest mention of American petroleum occurs in Sir Walter Raleigh's account of the Trinidad pitch lake in 1595, and the oil industry undoubtedly had begun in America long before 1632, when the Jesuit missionary Joseph de la Roche d'Allion noted the oil springs of southern Allegany County, New York, and said that the oil was highly prized by the Indians for medicinal purposes. However, nothing of a decided commercial value came of this until 1859, due to the lack of knowledge that petroleum often occurs in great quantities in the rocks, and of where and how to drill deeply into the earth to obtain it. The latter information was gained first through the early settlers in the Ohio valley searching for salt. Natural brines issued from the ground along the Little Kanawha River in West Virginia, and here in 1806 new drilling methods were devised to get at these deep-seated waters.

The first well, after much hard labor, was sunk to a depth of 80 feet by the lifting and dropping of a heavy chisel. Then the drillers found to their dismay that the brine was spoiled by an abundance of petroleum, to them a nasty and useless material. By 1820, drilling methods had been perfected so that 1000 feet of depth could be reached, but many of the salt wells were still rendered "useless" because of the oil, which dirtied the Kanawha to such an extent that it became known as "Old Greasy."

The accumulated knowledge of deep-well drilling and of the fact that rock oil occurs in commercial quantities deep within the earth's crust was made use of by Col. E. L. Drake and the Seneca Oil Company in 1859, in drilling to completion, near Titusville, Pennsylvania, the first well for the getting of rock oil. At 69 feet below the surface they obtained a flow of petroleum pumping at first 40 barrels per day and later 15 barrels. This oil sold at from $25 to $30 per barrel, but since then the price has been even lower than 75 cents per barrel. Here was the beginning of a new industry, one that the development of the gasoline motor was to swell to huge proportions.

Depth of Oil Wells. — Oil and gas wells have been driven down to 7600 feet, a maximum attained in West Virginia and in Europe; few, however, are deeper than 4000 feet, the great majority ranging between 500 and 3000 feet. Probably more than a million wells have been driven or bored in North America and during each of the past six years about 26,000 wells have been drilled. The piped holes are usually from 6 to 12 inches in diameter, though at Baku in the soft rocks the wells range up to 26 inches.

Successes and Failures. — A well that does not yield oil or gas in paying quantities is said to be a "dry hole," and it is estimated that of all those drilled at present about 20 per cent fall into this class. Drilling with the object of finding new productive territory is of a very speculative nature. In the old days of oil prospecting, one great producer was struck in about every 150 wells dug, but now, due to the accumulation of geologic knowledge, about one good well is obtained to every three sent down.

Duration of Wells. — All oil and gas wells, after a time — usually a short one — cease to flow and finally even the pumps can raise no oil. To-day there are in the United States upward of 200,000 producing wells. The average duration of wells is from four years in Texas to seven in Pennsylvania. Single wells, however, have been productive from 25 to 57 years. In the Appalachian region the average of production in wells in 1907 was about two barrels per day, and in California more than forty barrels. Good wells are those that yield several thousand barrels daily, and at Baku in the Caspian region great gushers yield from 50,000 to 170,000

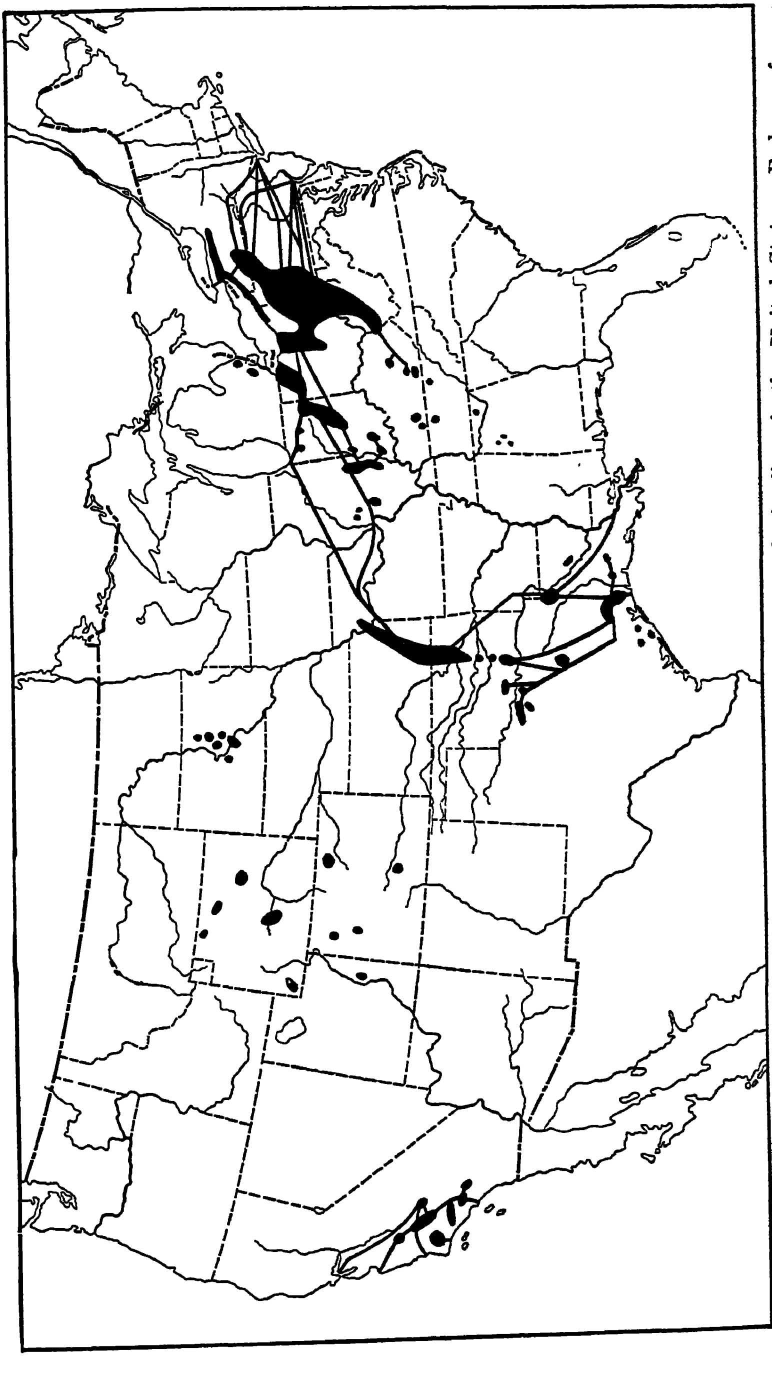

Fig. 75. — Map showing in generalized form the main oil and gas fields and pipe-lines in the United States. Redrawn from a large and detailed map published by the U. S. Geological Survey.

barrels, but at this rate only for a month or so, though one well gushed for seventeen months. The greatest of all the gushers was Cerro Azul No. 4, near Tampico, Mexico, which in 1916 yielded daily 260,000 barrels.

After a well has produced for some time, the internal pressure lets down and finally pumps are brought into use. Even so, all the oil that is concentrated into pools can not be recovered; at present, it is thought, not more than from 50 to 75 per cent.

The World's Great Oil Fields. — Since the days of ancient Greece, petroleum has been obtained from the western shore of the Caspian Sea (Baku) and south into Persia, and this region is still one of the richest in yield. In the United States, the industry spread from western Pennsylvania, after 1859, first south through the Allegheny Mountains, then throughout the Ohio and Mississippi valleys, with the greatest activity to-day in the "Mid-Continent Oil Field" (Kansas, Oklahoma, Texas) and California. With the increasing demand for petroleum, the search for productive strata has been carried into every continent, from the arctic areas of northwest Canada to the tropical East Indies, and from Japan to the Argentine. The most productive fields to-day, outside of our own country, lie in Mexico, Russia, Persia, and Venezuela, with those of Peru and the Dutch East Indies in rapid development.

Growth of the Oil Industry in the United States. — In 1859, the year when the present oil industry began, the United States produced 2000 barrels of crude petroleum; in 1870 the yield was 5,000,000 barrels, and in 1918 it had risen to the astonishing amount of 356,000,000 barrels, valued at $704,000,000, a natural national asset for that year as great as the combined values of gold, silver, copper, and zinc, and exceeded only by coal and iron. Moreover, the yield is still rising, and in 1920 equalled 450,000,000 barrels. The value of natural gas in 1918 was about $154,000,000, or nearly twice as great as that of lead. The pipe lines through which the crude oil and gas are transported total about 45,000 miles. Petroleum now comes from eighteen states, the leading ones being, in the order named, Oklahoma, California, Kansas, Texas, West Virginia, Illinois, Pennsylvania (once the greatest producer), Louisiana, Ohio, Wyoming, Kentucky, etc. The United States yielded between 1859 and 1918 about 60 per cent of the world's entire production of petroleum. Russia comes next with about 30 per cent.

Areal Extent of Oil Fields. — The present proved area of the oil fields of the United States amounts to about 4,100 square miles. The known new territory is estimated at 1000 square miles more,

and the future supply still in the ground at about 9,000,000,000 barrels (about 45 per cent prospective) all of which it is thought will be consumed during the next twenty years. The underground reserves in all countries are estimated by David White at 43,000,000,000 barrels, and this supply may last the world three hundred years. It is probable, however, that there is far more oil in the ground than is now believed.

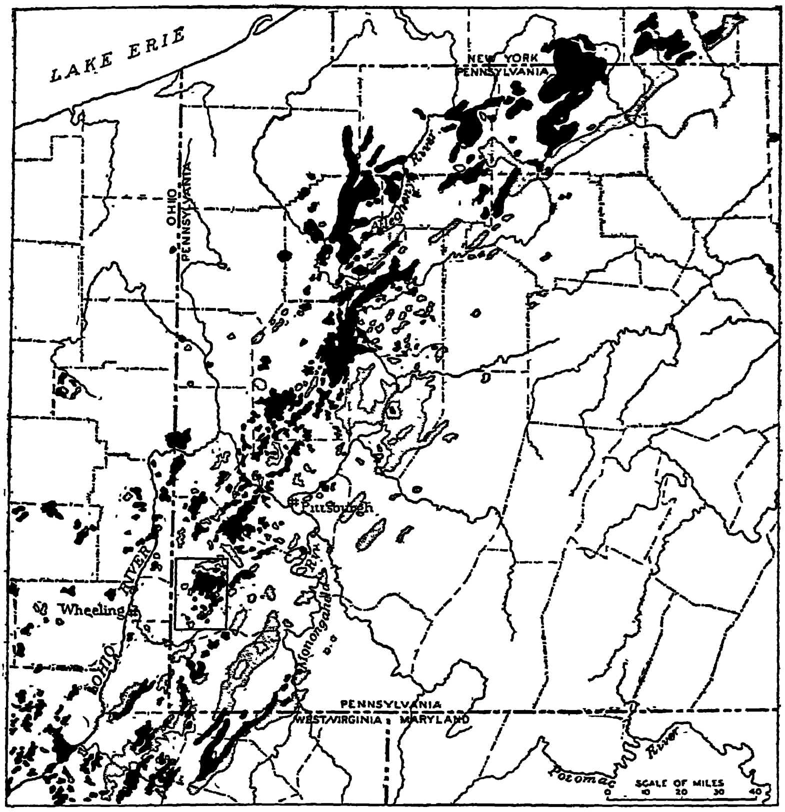

Fig. 76. — Sketch map of underground oil and gas "pools" in Devonian and Mississippian strata of Pennsylvania and adjoining states. Black areas, oil pools; dotted areas, gas. After M. J. Munn, U. S. Geol. Surv.

The Pennsylvania Oil Field as an Exemplar. — In the Upper Devonian of western Pennsylvania, West Virginia, Ohio, and New York, vast quantities of petroleum and natural gas have been obtained by drilling. This was the first exploited field in America. During the next forty-five years some 90,000 wells were driven at a cost of about $360,000,000, the yield in that interval being more than 750,000,000 barrels. The field is still productive, more than

twenty distinct horizons yielding petroleum. The map, p. 251, shows the areal extent of the underground pools. The oil and gas are stored in coarse, open-textured sandstones and conglomerates, and because of this the term *oil-sand* has come to be applied by drillers to all horizons yielding these volatile hydrocarbons. The number of underground oil-sand layers in a locality varies between one and three, and the productive wells are from 100 to 4000 feet beneath the surface. The oil and gas pools lie parallel to the principal geologic folds of the region.

Nature, Origin, and Distribution of the Natural Hydrocarbons

Natural hydrocarbons — natural gas, petroleum, asphalt, etc. — are mixtures of compounds of carbon and hydrogen. These mixtures are well-nigh universal in marine sedimentary rocks, but accumulations of petroleum in commercial quantities are rare. The hydrocarbons are likewise present in marine rocks which are not too much metamorphosed, but while free gases and oils are stored in sediments of fresh-water origin, no valuable deposits in such have so far been found. The greatest amount of the hydrocarbons occurs in a disseminated solid condition in the shales, especially in the fossiliferous black shales, where oil forms as much as 21 per cent of the rock mass. Even when only 3 per cent of the rock is petroleum it can be extracted by heating the shales and driving off the crude oil, and was so produced many years ago at a cost of 14 cents a gallon. Impure limestones, especially when dark in color, are full of oil, a fact at once noticeable on fracturing them with a hammer, when the odor of petroleum becomes apparent. Chicago is built upon a Silurian dolomite, and long ago T. Sterry Hunt estimated that each square mile of this rock one foot thick has more than 220,000 barrels of petroleum, and since the formation is 35 feet thick, each square mile has upwards of 7,500,000 barrels. Four square miles of this formation has more oil than all of the oil wells of Pennsylvania yielded between 1860 and 1870, or 28,000,000 barrels. These facts are recited to bring out the wide spread of petroleum in the marine strata, and yet the limestones have the smallest amounts. However, if the material is to be commercially valuable, it must be concentrated by natural agencies into limited underground areas and such invisible reservoirs must be discovered by the driller. For the distribution of the oil and gas fields in the United States see Fig., p. 249.

Petroleum. — The word petroleum means *rock oil*, and these mineral oils have long been known as Sicilian oil, as naphtha among

the Persians, and as nephtar among the Jews. They are used for power, for lighting, and for lubrication; about three hundred products are in fact made out of them.

Petroleum is a liquid bitumen, one of the hydrocarbons — a complex mixture of many compounds, principally of carbon (79–88 per cent) and hydrogen (9.6–14.8 per cent). There are two chief types of petroleums, one with a paraffin base and the other with an asphaltic one. The paraffin oils are lighter and more valuable, because they contain more gasoline and lubricating oils. Next to coal, petroleum is the most important of all the carbon compounds of the earth's crust.

Natural Gas. — This is an ideal industrial and domestic fuel, and is also used in the making of carbon black, pencils, and the carbons for electric arc lamps. Nearly all oil fields have gas, but there are gas fields that do not have petroleum in commercial quantities. In general, gas pools are far less wide in distribution than is petroleum. The pressure in a gas well is sometimes very high, as much as 2000 pounds to the square inch, though it is commonly much less. In Wyoming there are wells yielding more than 100,000,000 cubic feet of gas per day.

Other Hydrocarbons. — Gas and petroleum are the volatile natural hydrocarbons, and these gases and liquids, through more or less complete evaporation while underground, grade both chemically and physically into viscous and solid hydrocarbons. Natural wax or paraffin, known as ozokerite, is thus the solid residue of high-grade oil. Asphalt is another remainder of petroleum. Gilsonite, grahamite, and albertite are valuable black, brilliant, and solid hydrocarbons much used in the making of varnishes and enamels; they occur in veins up to 17 feet thick (albertite). Just as plants are preserved in all grades from peat to anthracite and graphite, so the decomposition products of plants and animals grade from gases and petroleum to solid hydrocarbons.

Original Source of Hydrocarbons. — It appears that the hydrocarbons are almost wholly of organic origin, since they are essentially the carbon and hydrogen residues of plants and animals. The proof of this statement follows on subsequent pages.

The bodies of living things, as is well known, are composed in the main of carbon, hydrogen, oxygen, and nitrogen. The plants extract out of the atmosphere the carbon for their bodies, while out of the ground they get the hydrogen and nitrogen, and much of these elements is finally stored away in the rocks as the hydrocarbon. How vast this migration of carbon has been throughout the geologic ages from the atmosphere into the living bodies of plants and animals, and hence to their dead remainders in the rocks, is

seen in the great amounts of carbonaceous materials in the sedimentary and essentially marine rocks, estimated to be thirty thousand times greater than the amount in the present atmosphere. Now let us see how the fatty materials of plants and animals come to be in the rocks.

During the life of plants and animals their daily chemical work results in some offal, and at death their whole bodies are subject to further change through bacterial decomposition. If this takes place directly under the atmosphere, decay is rapid and the decomposition products all return as gases and dust to the air and the ground whence they came. All rock formations which are accumulated directly beneath the atmosphere, such as the pure continental deposits, are therefore originally devoid of commercial quantities of petroleum, though subsequently such may migrate into them from adjacent marine strata.

All deposits, either of the fresh waters or of the seas, which are periodically subjected to atmospheric weathering during their time of accumulation, are lacking in oil in paying amounts. Hence the conclusion that all red or reddish, yellowish, or white, rain-pitted or sun-cracked deposits, either continental, fresh-water, or semi-marine in origin, are lacking in petroleum in large quantities.

Under water, and especially in marine water, bacterial decomposition of organisms is very slow, and as the fatty materials are freed, they tend to rise as tiny globules of oil. If the water is free of muds and is moved by currents, thus aërating it, the oil will be oxidized and escape into the air and be lost so far as the sedimentary rocks are concerned. If the waters be stagnant and muddy, however, then the tiny globules of oil will attach themselves to the clay particles and so sink to the bottom. Thus firmly locked together they will go forward toward the making of a dark bituminous shale. *The life of the seas is therefore the ultimate source of the petroleum.* The rising globules of oil have no affinity for the grains of quartz nor much for the precipitating tiny flakes of carbonate of lime. While probably only 10 to 15 per cent of all shales are black shales, yet these are of great importance, since they are the *mother rocks* of petroleum. The nitrogenous portions resulting from organic decay, however, rise through the water into the air and this is the reason why nearly all of them are absent in the petroleum. This affinity of oil for clay is, therefore, a constant force holding it in the shales or in the clay particles in sandstones and limestones. To liberate this oil again another force is needed, and we shall see later on that it seemingly is the pressure of capillarity that sets the oil free.

Proof that Petroleum is of Organic Origin. — That probably almost all petroleum and in fact almost all hydrocarbons are essentially derived from marine plants and animals, microscopic and large, is proved by the fact that they have the same optical properties as animal oils, that is, rotate the plane of polarized light. Charles F. Mabery says that the evidence for organic origin is even better shown in that most of the rock oils have up to 20 per cent of nitrogen derivatives, which could only have had their source in organic materials.

Dalton says that the optical activity of petroleum is due to cholesterol and phytosterol, and that the physical and chemical properties of these alcohols are both recognized in the oils. Not only do they establish beyond question the organic origin of petroleum, but also, since the alcohols in question occur in the fatty parts of animals and vegetables, they confirm Engler's hypothesis that these parts play the principal rôle in the formation of mineral oils.

Occurrence of Oil and Gas in Nature

Requisites for Oil and Gas Pools. — We will now describe more or less briefly the six primary requisites for oil accumulations. These are: (1) Dark bituminous rocks, the original source of the hydrocarbons, which are the chemical end-results of organic decay in marine waters. (2) Underground water, under either hydrostatic or gaseous pressure, as the dislodger of the hydrocarbons from the carbonaceous rocks, more commonly the black shales, and as the carrier of the oil, the water being in the main rain water that has filtered deeply and more or less widely into the rocks from the rain-soaked soils. (3) An internal rock pressure, either gaseous or hydraulic, that will force water with its load of hydrocarbons into the rising geologic structures. (4) Some sort of an ascending geologic structure, like those illustrated in the diagrams on p. 259. In these structures the grain or bedding of the rocks is ascending, which leads the water that is under pressure to carry the oil to locally higher levels, where the hydrocarbons find lodgment in coarse-grained rocks. (5) A porous granular formation like a sandstone, conglomerate, crystalline or cavernous dolomite or limestone, rarely a volcanic rock. These coarse-grained rocks make the "reservoirs" for oil and gas, and the local accumulations are the "oil sand," "oil pools," and "gas pools" of the petroleum geologists. Fractured or jointed rocks also lead to oil storage. (6) An impervious rock cover to prevent the volatile hydrocarbons from escaping into the air. These coverings are in most cases very fine-grained mudstones like shales or marls, or there may be a sealing agent in the rock cover, such as the interstitial cement of water-laid rocks. More often, however, it is the thickened or solidified hydrocarbons themselves that seal the reservoirs.

When the rocks are devoid of water, in which case they are said to be "dry," the gas separates from the heavier oil and rises to higher levels of the rock beneath the shale cover, while the oil gravitates down the dipping slopes of the strata to lower levels and segregates in the more porous areas, where oil "pools" are formed (see Fig., p. 259). The oil or gas may accumulate in pay layers of rock as thin as 2 feet, or in rare cases (California) the productive stratum may be 200 feet thick. The pools in dry strata are more irregular in distribution than those in wet formations. When a large quantity has concentrated there seems to be a tendency for the pools to seal themselves at the top, and, if more and more oil and gas are added from below, the "rock pressure" rises above the hydraulic pressure or "head" produced by the water of circulation. Lower "rock pressures" are the rule, from 350 to 500 pounds to the square inch, but they are known up to 2000 pounds to the square inch (in newly tapped gas wells). Hydrocarbons may also be driven to higher levels by the heat of subterranean bodies of intrusive igneous rock, or by chemical alterations within the strata, but such fields are the exception.

The storage of oil in "pools" takes place in the original pores of the strata, or in induced spaces developed through solution by circulating waters. The original porosity results from the unfilled interstitial spaces between the grains or pebbles of which the rock is composed, or where a filler or cement has been subsequently dissolved out. Induced porosity results from water percolating through limestones along erosional unconformities, between bedding planes in thin-bedded formations, through the solution holes of dolomites, through the spaces between dolomite and calcite crystals developed during diagenetic changes, or in joints and tension cracks, and along fault and dike faces.

Extent of Migration. — There is little evidence indicating exactly the extent to which oil and gas have migrated through the strata. Geologists in general hold that it has not been far, that the hydrocarbons probably have not been moved more than hundreds of feet and rarely miles in extent. Some field men, however, say that there is evidence that oil has been moved 2 or 3 miles up the flanks of rising geologic structures, and in Wyoming even as far as 15 miles. The migration probably takes place quickly in geologic time, and apparently immediately after deformation of the strata. The oil then remains localized for countless ages or until another warping or folding time occurs. During the geologic past, however, all parts of the continent have been repeatedly moved.

Geologic Structure of Oil and Gas Areas. — Oil and gas are more commonly found in the flattened tops of depressed geologic arches

and local domes and down the slopes of anticlines where the dip of the strata is arrested so as to form shelves or terraces (the "terrace structure" of oil experts); they occur also in sandstone lenses, in the upturned strata of faulted formations, along dikes of igneous rocks penetrating sediments, and on the peneplained surfaces of arches covered by younger formations.

The anticlinal theory was first suggested by T. S. Hunt (1863) and E. B. Andrews (1865), and put into good working order by I. C. White (1885). This theory as originally stated by White is as follows: All of the great gas wells of Pennsylvania and West Virginia are situated either directly on or near the crown of an anticlinal axis, while wells bored in the synclines on either side furnish little or no gas, but in many cases large quantities of salt water. The gas wells are confined to a narrow belt, only one fourth to one mile wide, along the crests of the anticlinal folds. They are therefore connected unmistakably

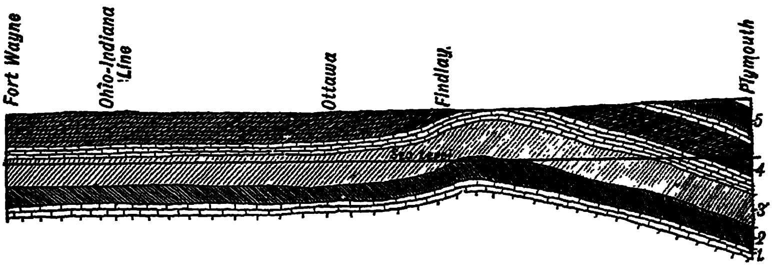

Fig. 77. — Geologic section through Ohio-Indiana oil and gas fields. The arch is the Cincinnati uplift. 1, Trenton limestone, the reservoir into which the hydrocarbons have migrated from a higher level; 2, the impervious cover to the reservoir, here shales of the Champlainian (Utica and Eden); 3, Upper Champlainian; 4, Silurian limestones and dolomites; 5, Devonian limestone and shales. After Orton, U. S. Geol. Surv.

with the disturbance in the rocks caused by the upheaval into arches. It does not follow, however, that all arches have gas or oil, since pools of these materials are dependent on the presence of thick porous sandstones or extensively fissured fine-grained rock, to act as reservoirs; and these storage rocks must underlie the surface at a depth of at least several hundred feet. In Paleozoic formations the arches must be of the depressed type and outside of mountain tracts, since in the areas of the ancient mountains the gases and the oil have long since escaped from the folded strata into the air and their residues dried up. In the mountains of late Mesozoic and Cenozoic time, however, much oil and gas remain. Finally, the areas of commercial pools must have formations close at hand of bituminous shale, since it is from these deposits in the main that the hydrocarbons have migrated.

Water, the Migrating Agent. — Moving water is the essential agent of migration. This migration takes place either (1) through the migratory action of water driven by hydraulic pressure; (2) through the capillary powers of water and oil in coarse- and fine-

grained rocks; or (3) through the specific gravity of oil and water, whereby these come to be locally segregated. In dry rocks gas will rise into the higher places, while oil will sink into the lower ones or into synclines, because of the difference in their specific gravities. All strata during their deposition are full of water, and through their subsequent consolidation and compression more or less of the water is squeezed out and upward. In its movement, it carries some oil with it, and this becomes lodged in the greater pore space of the porous rocks. Under the conditions of compression, cementation, and increasing heat, these factors probably combine to cause further upward movement of the oil and water. The general effect of this migration is to increase the percentage of oil in the sandstones at the expense of the shale, and to drive out from the strata a greater ratio of water than oil, which further increases the percentage of oil to water in the sandstones, yet probably leaves a large amount of oil in the shales (Munn).

"The fundamental idea of the hydraulic theory is that moving water under either hydraulic or capillary pressure has been the direct agent of accumulation of oil and gas pools. To this idea may be added another of equal value — the pools of oil and gas are held in place by water under hydraulic and capillary pressure which effectively seals up all the pores of the surrounding rock and prevents the dissipation of pressure by diffusion" (Munn).

Oil Shales. — There is a great deal of anxiety at present because of the fact that the oil territories are being rapidly exhausted. It is said that during the past sixty years the United States has used up 40 per cent of its available petroleum reserves. This may or may not be so. Such rapid exhaustion of the petroleum leads most geologists to the belief that when all is used up, and it will be with present demands about twenty years hence, there will be no gasoline, illuminating, or lubricating oils. There need be no immediate fear of this, however, because when the present oil fields are used up, the nations can still have as much petroleum as they care for, but of course at enhanced prices, since there is an inexhaustible amount of petroleum available in the black bituminous shales, the pyroshales (burning shales), and the cannel coals or torbanites. The United States and Canada are especially rich in such resources. The Paleozoic formations of the Mississippi valley, the Cretaceous of western Canada, and especially the wide-spread Eocene (Green River) shales of Utah, Wyoming, Colorado, and Nevada, abound in these petroliferous rocks. Out of them can be produced petroleum, heating and illuminating gas, and ammonium sulphate as a fertilizer. It is said that the black shales about Louisville, Ken-

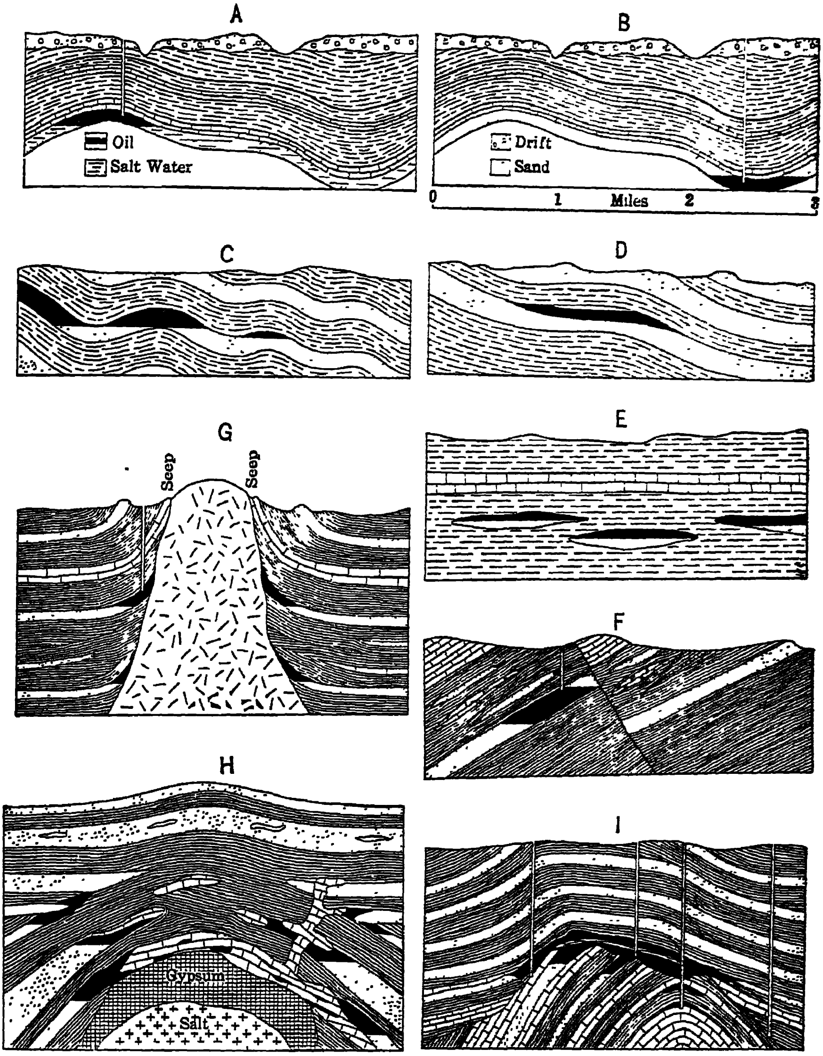

Fig. 78.—Diagrams to show relation of oil accumulation (black) to geologic structure. *A*, anticline with water and oil pool (after Savage). *B*, syncline with oil, but without water (Savage). *C*, oil pools on crest of minor arches on the flank of an anticline (Smith). *D*, oil pool on terrace structure (Smith). *E*, oil pools in sand lenses in shale formation (Smith). *F*, oil pools in faulted strata and lenses of sandstone (Semmes). *G*, oil pools on either side of a volcanic neck or dike (Semmes). *H*, oil pools of a salt dome (Fenneman and Semmes). *I*, oil pools over an eroded mountain fold in the Healdton field of southern Oklahoma (Powers and Semmes).

tucky, have in them something like 7,000,000 barrels of oil to each square mile of shale. The problem at present is how most economically to get the oil out of the shales.

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CHAPTER XXI

SILURIAN TIME AND THE FIRST AIR-BREATHING ANIMALS

The Term Silurian. — The term Silurian was proposed in 1835 by the great English geologist, Sir Roderick Impey Murchison, who was for a long time the director of the Geological Survey of Great Britain. The area where these rocks were first studied is the border land between England and Wales, the home of the ancient Silures, a Celtic race who fought Cæsar's legions.

Fig. 79.—Roderick Impey Murchison (1792–1871). Author of Silurian, Devonian, and Permian systems.

History of the Term Silurian. — Previous to 1835 the geological column had been determined down to the Old Red sandstone, the continental phase of the Devonian, the equivalent marine phase having not yet become known. Below lay a great complex then known as the "Primitive Series." On the border land between England and Wales, the "primitive" rocks were least disturbed and many of them abounded in fossils. Early in his studies Murchison found that the highly fossiliferous portion represented a system not known before to Geology. At the same time he urged his colleague, Sedgwick, to give the name *Cambrian* to the greater mass of the greywackes that both men then thought to be older than any part of the Silurian. This was done late in 1835. Even if the proper sequence of the formations was then very inadequately understood, what was made known marked an epoch in Historical Geology. In 1838 Murchison published his "big book," *The Silurian System*, a classic of 800 pages, while Sedgwick delayed until 1855 the printing of his great work, *Synopsis of the Classification of the British Rocks.*

Murchison subdivided his "Silurian System" into an upper and a lower portion, but his Lower Silurian formations were essentially of the same age as the series in the north of Wales that Sedgwick was calling Upper Cambrian. Nor did Murchison see that an angular unconformity separates the Lower from the

Upper Silurian, and it was Sedgwick who first showed such a relationship. These differences inevitably led to a controversy which was not adjusted until 1874, when Lapworth restricted the term Silurian to Murchison's Upper Silurian sequence, leaving Cambrian to be applied, as usage had brought about, to Sedgwick's Lower Cambrian, and proposing for Sedgwick's Upper Cambrian and Murchison's Lower Silurian the term *Ordovician*.

The upper boundary of the original Silurian also long remained undefinable because of the absence of marine fossils, and because of the erroneous opinion that here there was a transition series passing unbroken into the fresh-water Old Red sandstone. The adjustment was first made in Germany by Kayser (Harz region), in France by Barrois and Pruvost in 1919, and in Shropshire and southern Wales by Stamp in 1920. The result is that all of the "passage beds" (Temeside shales at the top, followed beneath by the Downton Castle sandstone = Tilestones, and the Ludlow bone bed) are now referred to the base of the Lower Devonian. The Silurian of the type area, therefore, now ends with the Chonetes flags of the Upper Ludlow. On the basis of these determinations, the upper boundary of the Silurian in America is in this book regarded as beneath the Manlius formation.

General Characteristics of the Period. — The Silurian system of strata lies upon the Champlainian and beneath the Devonian. Silurian time is far shorter than Champlainian. Almost everywhere in North America the strata of the Silurian system are easily separated from the Champlainian below by a more or less long "break" or interval. An angular unconformity occurs between them from Port Jervis (see Fig., p. 263), northeast to Kingston and Becraft, New York, but in the New England States and the Maritime Provinces of eastern Canada the reported angular nature of the break has not as yet been established. In the great interior region of the continent the separation, as a rule, can be made only on the basis of the entombed fossils (see Fig. 82, p. 265). On Anticosti Island in the Gulf of St. Lawrence may be studied the most complete American section. Even here, however, the two periods are separated by a break.

North America during the Silurian had about the same general topographic expression as in Champlainian time, that is, the greater interior basin region stood but little above sea-level, while the highlands, as heretofore, were toward the margins of the continent. Twice was the interior low area transgressed by great floods, first during the Alexandrian epoch and later during the Niagaran epoch, when from 35 to 40 per cent of the continent was under water. These floods came in the main from the Arctic, spreading south into the United States, while smaller seaways spread from the Gulf of Mexico northward. There were also small seaways in the St. Lawrencic and Acadic geosynclines that were flooded by the Atlantic

Ocean. At different times the St. Lawrencic marine waters connected with those of the Appalachic trough. Of the Cordilleric seas little is known.

The life of the Silurian, while prolific, is not so varied as that of the Champlainian. The Silurian strata abound in invertebrate marine animals, but now more land plants are present and land animals (scorpions and thousand-legs) make their first appearance, with a considerable variety of fresh-water fishes. From this time onward, we shall see wider and wider home-making on the lands by the emerg-

Fig. 80. — Champlainian-Silurian unconformity at Otisville, N. Y. Above are conglomeratic sandstones (Shawangunk), resting on the peneplained surface of Champlainian shales (Martinsburg). The difference of dip between the two sets of strata is about 15°, and this unconformability is due to the Taconic emergence.

ing life of the waters. The climate was in the main warm, moist, and equable, but in the last Silurian epoch (Cayugan) it became arid over very wide regions; furthermore, the seaways during this epoch were small. In consequence, the almost land-locked parts of the epeiric seas deposited during Cayugan time in eastern North America much gypsum and salt. The last of the Silurian seas were very small shifting ones in the Appalachic geosyncline and elsewhere, and they appear to have continued uninterruptedly into Lower Devonian time.

Toward the close of the Silurian all of western Europe was in the throes of a most marked time of mountain making, giving rise to the Caledonian and other chains of grand mountains. These movements also naturally affected the climate, and there is evidence of glaciers and winters in northern North America.

Cincinnati Uplift. — This low arch, described in Chapter XIX, was not a marked topographic feature in the seas until after Lower Silurian time (see pp. 241, 273), when distinct marine basins lay on either side of it. Floods from the Gulf of Mexico extended northward and covered the areas to the east and west of the arch, but along the western side the waters were most persistent during the Niagaran epoch.

TABLE OF AMERICAN SILURIAN FORMATIONS

America					Great Britain
Apparently no break with Devonian in Appalachian area					
Cayugan or Upper Silurian		Rondout, Cobleskill	Tonoloway	Monroan	Ludlow series, Aymestry limestone
		Bertie-Rosendale			
		Camillus shale and gypsum, Syracuse salt, Vernon-Pittsford	Wills Creek-Bloomsburg-McKenzie	Salinan	
Marked shifting and reduction of seas					
Niagaran or Middle Silurian	Lockport	Guelph-Brownsport, Waldron-Laurel-Racine		Lockport-Louisville	Wenlock-Woolhope
	Clinton	Rochester-Osgood, Middle and Lower Clinton		Lakemont-Rockwood	Tarannon-Upper Llandovery
Great but not complete emergence followed by greatest submergence					
Alexandrian or Lower Silurian		Cataract-Brassfield-Severn, Edgewood-Becsie-Gun River, Girardeau		Medina-Clinch-Tuscarora-Shawangunk	Lower Llandovery and Lower Birkhill
Complete break with Champlainian					

Character and Thickness of Silurian Rocks

Eastern United States. — In the Appalachic trough the sedimentaries are coarse-grained throughout until near the close of the Silurian, when much compact or dense cement rock (water limestone) was deposited in very shallow seas, as is indicated by its decidedly sun-cracked nature. These coarse-grained rocks are the results of rapid erosion from the high lands of Appalachis and Acadis following the emergence of late Champlainian time. In east-central Pennsylvania the thickest accumulations occur, with a maximum of 6490 feet. Of this mass the lower 4490 feet are almost devoid of limestones,

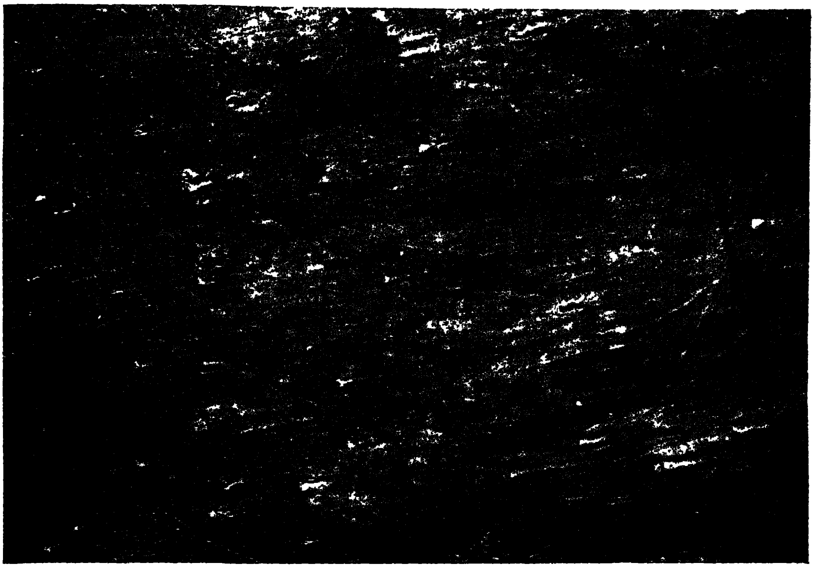

Fig. 81. — Silurian sandstone (Medina) showing fine wave lines of a beach, and scattered Lingulas. An actual piece of Silurian shore, from Lockport, N. Y. Original in New York State Museum. Photograph from John M. Clarke, Director.

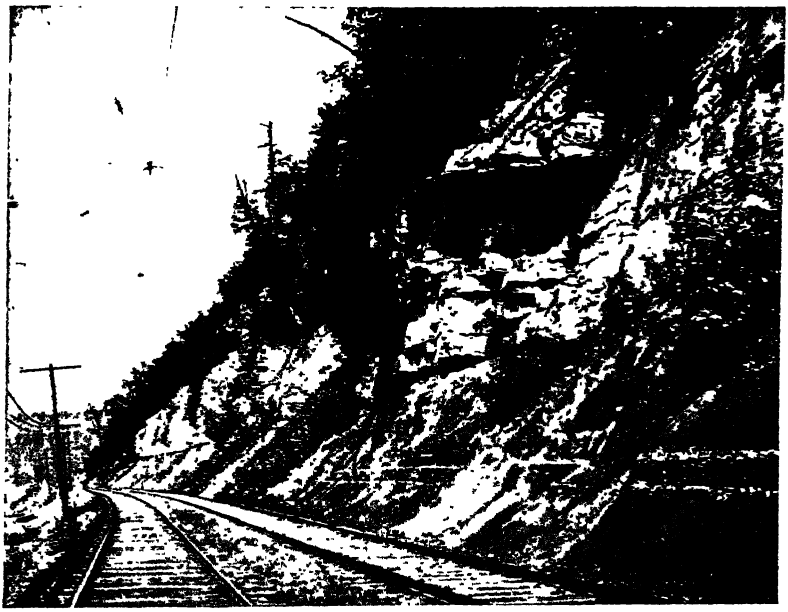

Fig. 82. — Champlainian-Silurian disconformable contact, Niagara River gorge, N. Y. Note even contact of white Silurian sandstone (Whirlpool-Cataract) on brick-red, sandy, Champlainian shales (Queenston).

the strata being cross-bedded sandstones, sandy shales, shales with a little sandy limestone, and, toward the top of the series, local beds of valuable fossil iron-ore. The upper 2000 feet of Upper Silurian age consist of shales gradually becoming more and more calcareous toward the top, which, in New York, Ohio, and western Ontario, bear valuable deposits of rock salt and gypsum.

This great mass of Silurian material thins rapidly to the south and north and probably also to the west under the coal fields of the Allegheny region. In the Niagara Falls area of New York there are about 180 feet of shale, sandstone, and dolomite that thicken rapidly to the south under the cover of the younger strata (see Fig. 84, p. 268). At the Virginia-Tennessee line there are not more than 400 feet of basal sandstone (Clinch) followed by 325 feet of shales and sandstones (Dyestone). South of Tennessee these beds again thicken, there being in the Appalachic trough of northwestern Georgia 1600 feet of Lower and Middle Silurian strata which thin rapidly to the west end of the state, where 180 feet are present.

Acadis. — In the Acadic trough the Silurian is widely spread and often rich in fossils. A thick section is exposed at Arisaig, Nova Scotia, where there are nearly 4000 feet of shales and sandy limestones. In southeastern Maine the Silurian is locally very thick, there being in the Eastport region about 10,000 feet of volcanic tuffs and detrital land sediments. This thickness, however, does not include the volcanics and lava flows, which also have considerable depths.

Another fine exposure of Silurian strata is that of Anticosti Island. It is, however, in the St. Lawrencic trough, with more than 1200 feet of limestones and some shales representing the earliest portion of the American Silurian; the higher beds continuing the section are present farther southwest along the north shore of the Bay of Chaleur, Quebec. At Black Cape the Silurian is about 7000 feet thick and is terminated by lava flows.

Silurian Sequence at Niagara Falls. — Between Buffalo, New York, and the region about Niagara Falls may be studied a typical Silurian section and one of the finest exposures in America for strata of this time. The gorge between the Falls and Lewiston has the lowest strata reposing on the Champlainian, while the younger deposits appear in sequence toward Buffalo, where some of the Middle Devonian is also to be seen in the Bennett quarries. The floor of the "Cave of the Winds" beneath the American falls is of Clinton limestone, and the Niagara River dashes over the basal sandstone at the Whirlpool Rapids. The diagram, page 268, shows the sequence of the beds and the figure, page 267, pictures them as they appear in the walls of the gorge of Niagara River. All of the strata have a gentle dip southward.

Interior of North America. — Here the Silurian seas had clear waters, and their deposits were almost entirely calcareous. Almost all of them were of Middle Silurian time. The strata were widely

distributed in two epeiric seas, one being the smaller southern Central Interior sea and the other the far larger sea of the Arctic region. Nowhere are these deposits thick when compared with those of the Appalachic trough, and, unlike the latter, they are largely limestones, dolomites, and calcareous shales, with almost no sands. In no place does the thickness exceed 1000 feet and in general it is usually considerably under 500 feet.

Rocky Mountains. — The Silurian of western North America is not yet well known and appears to be poorly developed throughout the United States. In

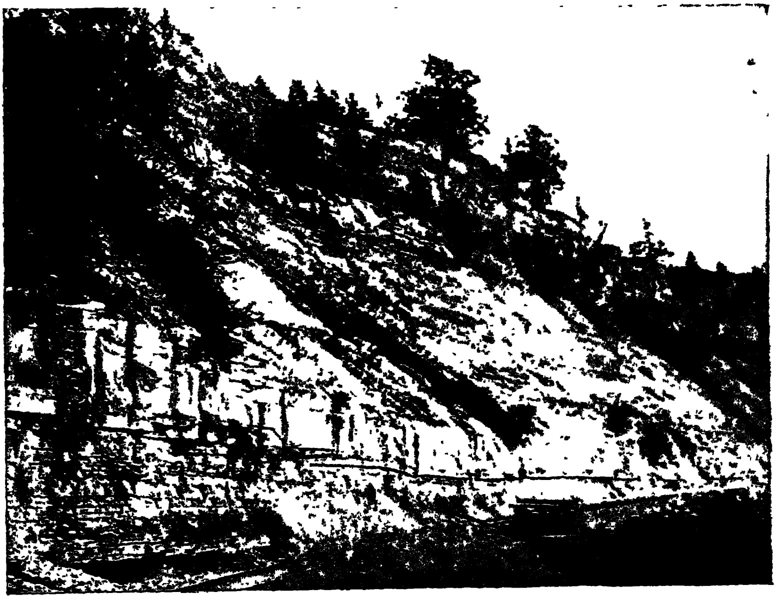

Fig. 83. — General view of New York side of Niagara River gorge. Clinton limestone at track level, the long slope is Rochester shale, and the vertical upper walls are Lockport dolomite, here about 25 feet thick; at the falls the Lockport is 80 feet thick, but its total thickness is 130 feet. Fig. 82, p. 265, continues these strata to the base of the Silurian.

the Cordilleric sea of Canada, however, there was another deep trough, for near the International Boundary (Bow Pass) there are 1300 feet of dolomites and quartzites. This trough deepened northward, since in the western Mackenzie valley (Gravel River) there are 2000 feet of dolomites, and in Alaska at the Lower Ramparts of the Porcupine River there are 2500 feet of dolomites with some black shale. In southern Alaska in the region of Kuiu Island there are 2000 feet of limestone. It is in this region that tillites occur, as described on page 277.

In the southern portion of the Cordilleric sea little is known of the Silurian deposits, but such are seen to occur in Nevada and in the Utah area of the Great Basin, where 200 to 300 feet of magnesian limestones have unmistakable Silurian

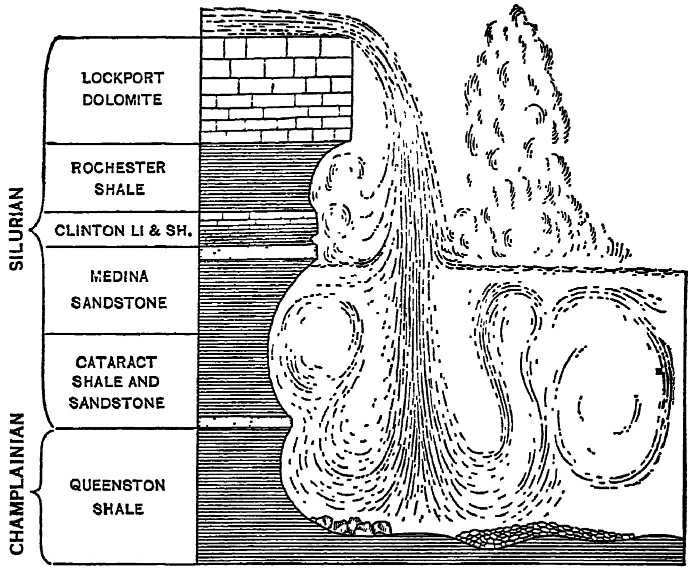

Fig. 84. — Sectional diagram through Horseshoe Falls, Niagara River, showing sequence of formations and depth of water below falls. Height of falls, 158 feet; depth of water, 150–200 feet. Modified from G. K. Gilbert.

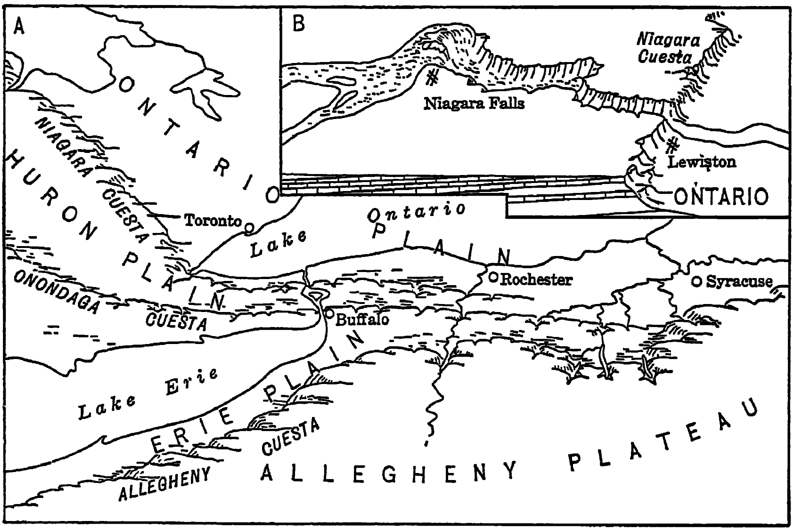

Fig. 85. — Present physiography of the Niagara Falls region. Note in A the three successive cuestas, and that the river goes over the two lower ones. B shows 7 miles of the Niagara River area, enlarged to a still greater scale. The falls have eroded back from the Niagara cuesta. After A. K. Lobeck.

fossils. In the Franklin Range of western Texas there is another Silurian area of a distinct sea, also apparently of Pacific origin; here there are 1000 feet of Middle Silurian limestones.

Life of the Silurian

Marine Provinces. — On the basis of their entombed faunas the American Silurian deposits are geographically divisible into four provinces. These are (1) Atlantic, (2) Southern, (3) Arctic, and (4) Cordilleran (see p. 273). The best known of these, with the longest and least broken record, is the Southern province, embracing the Silurian deposits of the southern portion of the Central Interior sea and the Appalachic trough. The Arctic province, of Lower and Middle Silurian time, includes much of the northern interior part of the continent south almost to the Ohio River, and has decided faunal connections with the Baltic area of northern Europe, the intercommunication being by way of northern Greenland, and the St. Lawrencic trough. In the Cordilleric sea the Silurian faunas are not well known, but appear to be of Pacific origin.

Marine Invertebrates. — As is usual in marine sediments, practically nothing of the soft seaweeds is preserved, although the Silurian life record is almost entirely that of the shallow sea wherein these plants abound. The invertebrates still dominated the seas, because the fishes were as yet not at all common though appearing more abundantly in the late Silurian rocks of Europe. Upward of 2500 species of invertebrates have been described from the American Silurian, the common ones being mainly corals, crinids, bryozoans, brachiopods, and trilobites (see p. 270). Of nautilids there are fewer than a hundred kinds known in America, although the Silurian in other parts of the world (especially Bohemia) was the time of greatest nautilid development, and since then there has been a steady decrease in number of species. True graptolites were still common in the European seas, but in America they are not often found as fossils.

Of crinids there are nearly 400 kinds known in the American Silurian, a far better development than in the Champlainian. The bryozoans were also common, but while they made small reefs in the Clinton, they were not so prolific as in the Champlainian (see Fig. 87, p. 272).

Of brachiopods there are more than 350 kinds described from the Silurian of America (see Pl., p. 270, Figs. 5–14). Although their general development was still much like those of the Champlainian, they were, on the average, larger and more robust. There was also at this time a distinct change in the introduction of many

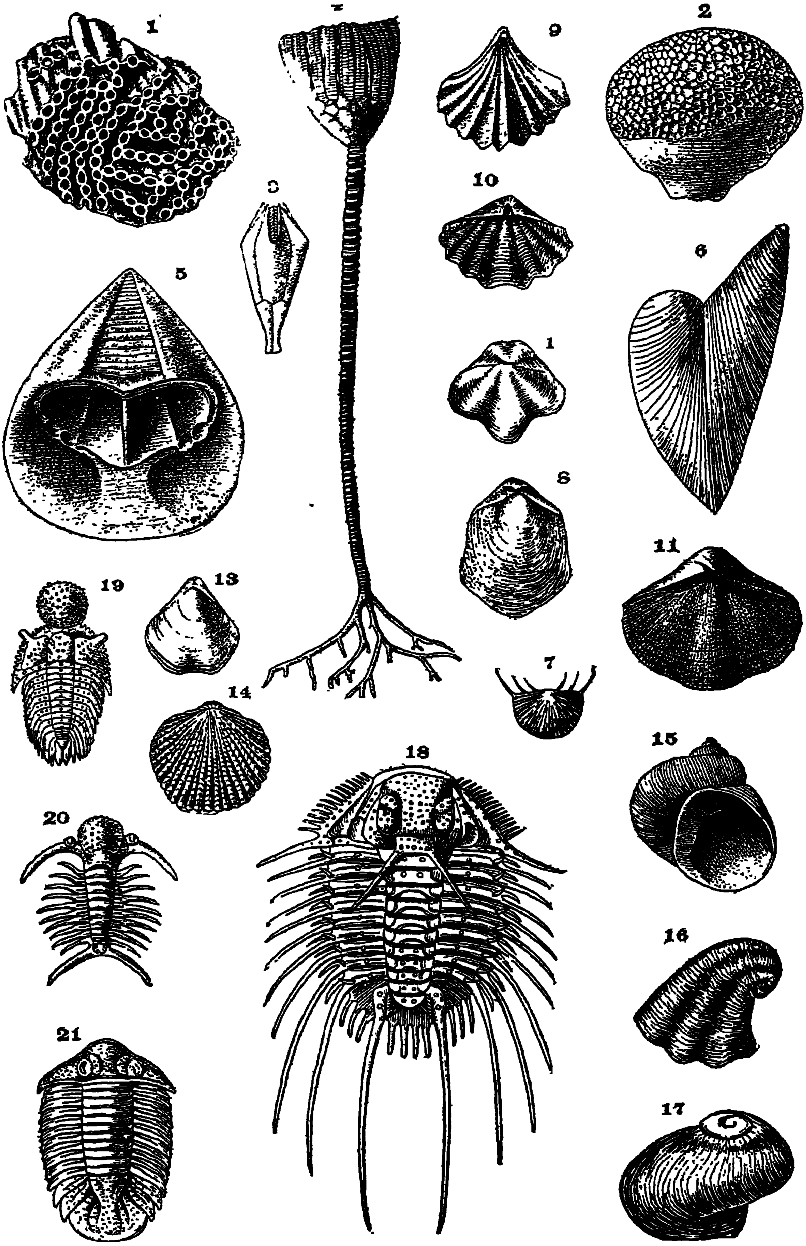

Plate 13. — Silurian corals (1, chain coral; 2, honeycomb coral), blastid (3), crinid (4), brachiopods (5–14), gastropods (15–17), and trilobites (18–21).

Fig. 1, *Halysites catenulatus;* 2, *Favosites occidentalis,* × $\frac{3}{4}$; 3, *Troostocrinus reinwardti;* 4, *Eucalyptocrinus crassus,* × $\frac{1}{3}$; 5, 6, *Monomerella noveboracum,* × $\frac{1}{2}$; 7, *Chonetes cornutus;* 8, *Pentamerus oblongus,* × $\frac{1}{3}$; 9, *Rhynchotreta americana;* 10, *Spirifer crispus;* 11, *S. radiatus,* × $\frac{2}{3}$; 12, *Hyattidina congesta;* 13, *Whitfieldella nitida,* × $\frac{1}{2}$; 14, *Atrypa nodostriata;* 15, *Strophostylus cyclostomus,* × $\frac{2}{3}$; 16, *Platyceras angulatum;* 17, *Diaphorostoma niagarense,* × $\frac{1}{2}$; 18, *Ceratocephala dufrenoyi;* 19, *Staurocephalus murchisoni;* 20, *Deiphon forbesi;* 21, *Metopolichas breviceps,* × $\frac{1}{2}$.

Mainly after the New York and Indiana State Surveys. Also from Scott and Zittel.

forms that have internal spiralia or calcareous supports for the arms (p. 216) and in the abundance of rhynchonellids and pentamerids.

Of trilobites there were still at least 105 American species, many of which were bizarre looking animals with many spines on the head and tail (see Pl., p. 270, Figs. 18–21). Spinosity is often interpreted as indicating an ebbing of the vital force among the trilobites, but in some forms it may have been a protective device against the carnivorous fishes then coming into being.

Throughout the Silurian, but more particularly in the Upper Silurian, the "sea scorpions" or eurypterids were common (see p. 276). They usually occur in brackish-water deposits that otherwise are devoid of fossils, and very similar kinds are found in both eastern America and western Europe. Their immediate ancestors appear to have been marine animals, but after Silurian time they are usually found in fresh-water deposits. The largest American species is found in New York (*Pterygotus buffaloensis*), where Clarke and Ruedemann have determined for it a length of nearly 9 feet. The eurypterids are particularly interesting in this connection, not only because they are so characteristic of late Silurian time, but also because they indicate the stock out of which in an earlier period arose the air-breathing or true scorpions.

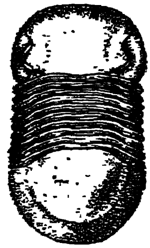

Fig. 86. — A characteristic trilobite of the Middle Silurian (*Illænus ioxus*), about one sixth natural size.

Coral Reefs. — Corals were not common until the Middle Silurian, and then at many places in America they made reef limestones (see Fig. 88, p. 272, and Fig., p. 183 of Pt. I). The best examples of these are seen in Wisconsin, Iowa, and the Manitoulin Islands, and to a more limited extent at Louisville, Kentucky. All of these corals are of the kinds known as Tabulata and Tetracoralla, described in the next chapter.

Associated with the coral reefs, more especially toward the close of the Middle Silurian (Guelph), are seen many thick-shelled animals, most of which are gastropods. Fifty species of these have been described from a limited area in Ontario. Similar associations are seen on the present living reefs, where the molluscs form thick shells, not only because they are necessary against the crushing power of the active waves, but also because there is much lime in the warm sea-water which can be easily extracted.

Cosmopolitan Character of Middle Silurian Life. — The known marine life of Lower Silurian time is scanty, but that which can be found indicates that each area had its own peculiar assemblage.

Fig. 87. — Small reef made by bryozoans, Niagara River gorge, N. Y. The reef (15 feet long) rests on Clinton limestone and projects into Rochester shale. There was no break in deposition between limestone and shale.

Fig. 88. — Silurian coral reef in Niagaran limestone (Racine), at Wauwatosa, Wisconsin. Note the bedded limestone on the left, merging into the reef limestone on the right. U. S. Geol. Surv.

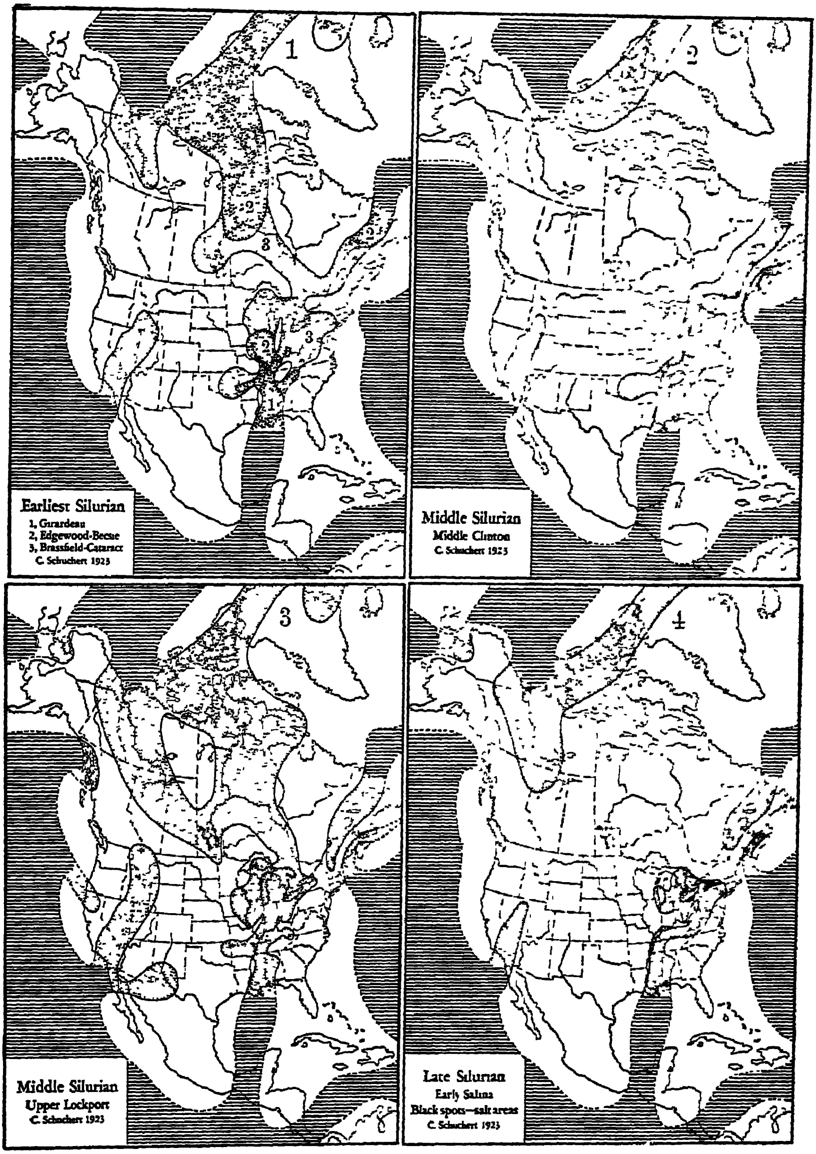

Plate 14. — Paleogeography of Silurian time.

Epeiric seas dotted; oceans ruled.

Map 1 shows three different stages in the flood of Alexandrian time. Maps 2 and 3 show the progression of the second flood, while Map 4 has the lingering seas at the close of the period, some of which were salt-making basins (the three black spots) during the arid conditions of this late Silurian time.

The same is also true of the earliest Middle Silurian faunas, but it is not so marked as in the earlier time. Finally, when the inundation of the continent was greatest, in Middle Silurian time (p. 273), the faunas of all the provinces took on a more cosmopolitan appearance and had the greatest number of species in common.

First Land Plants. — The known land plants of Silurian time are as yet exceedingly few, and the specimens are rather indistinct, but our knowledge of them is better than the fragmentary evidence of the Champlainian. Nevertheless, their abundance in the Devonian indicates that there were many land plants living in Silurian

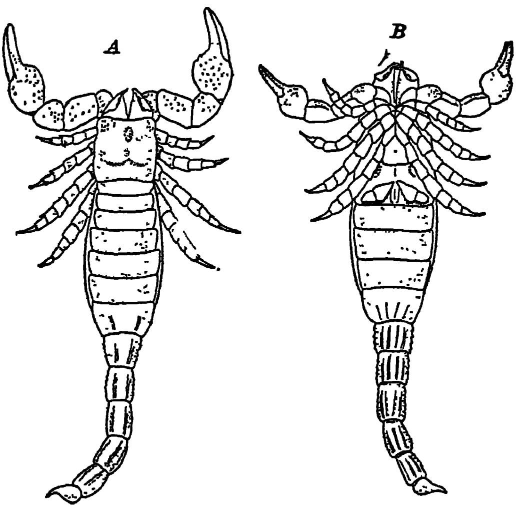

Fig. 89. — Two species of Silurian scorpions, restored. *A*, dorsal side of a Swedish form (*Palæophonus nuncius*). *B*, an English species (*P. hunteri*) from the ventral side. After Pocock.

times. The discussion of the nature of the first land flora is deferred to a later chapter.

First Land Animals. — *Fishes* undoubtedly lived in the fresh waters throughout this period, but nothing is known of them until late in Silurian time, when their skeletons are met with in Europe and very rarely in America (the *Onchus* of Claypole is not from the Clinton but from the Cayugan). As they are so much like those of the Devonian, a description of them is postponed until a later chapter.

The *scorpions* of the Silurian are the oldest known air-breathing animals (Fig., above). They probably had their origin in the eurypterids of the sea, seemingly as early as the Champlainian. The largest one known was 2.5 inches long, and in general structure they

were very much like the living scorpions, which live entirely on land. The question therefore arises: Were the adult Silurian scorpions wholly adapted to the dry land, or did they live along the seashore between the tides? Their remains are rarely found in marine deposits, but usually in those of brackish water and associated with the eurypterids, which would seem to indicate a littoral habitat. Scorpions are carnivorous animals, and the living forms feed on insects, spiders, and other small forms, killing the prey with their poisonous tail sting. We may assume that the Silurian species lived as do those of the present, and, as the latter are wholly terrestrial, the further question suggests itself: On what could the Silurian forms have fed, since no insects, spiders, or even land snails are known at this time, or for that matter previous to the Carboniferous? As spiders are closely related to scorpions, and as species of the former are known along most sea-coasts, inhabiting the beach between high and low tide, it seems, therefore, a safe inference that the Silurian scorpions also fed and lived, when adult, above the strand-line, though, like frogs, they may have lived in the water during their period of infancy, and that they ate small invertebrates, among them trilobites and small crustaceans.

Other air-breathing animals are the *thousand-legs* (myriapods) found in the late Silurian strata of Wales in association with eurypterids. Their next known occurrence is in the Old Red sandstone of Scotland.

Silurian Climate

As the Silurian seas abounded in varied life and as the deposits in the main were limestones and dolomites even as far north as the Arctic regions, it is safe to infer that these waters were warm. Additional confirmation is had in the fact that the life of the American Arctic deposits is very much like that of northern Europe and of the United States, while the reef-building corals are practically everywhere the same. The chain coral (*Halysites*, Pl., p. 270, Fig. 1) and the honeycomb coral (*Favosites*, Fig. 2) are very similar in all the areas, and are found even above 81° north latitude at Polaris Bay. Further, extensive salt-depositing seas existed in eastern North America between 40° and 45° north latitude, indicating an arid or dry climate on the land, though it is not necessary, because of this evidence, to assume that the temperature was hot. We may therefore conclude, on the basis of the character of the deposits and of the life, that the climate of Silurian time, in the northern hemisphere at least, was temperate to warm.

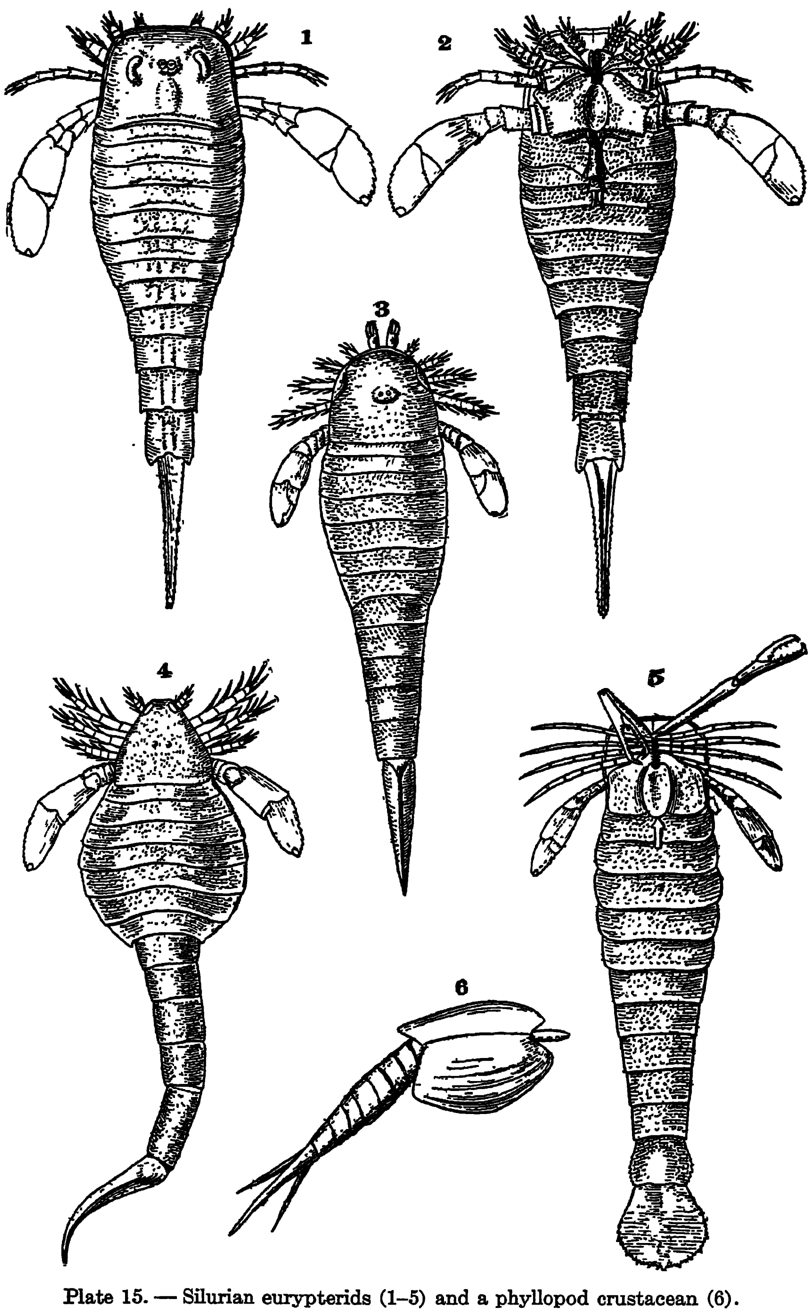

Plate 15. — Silurian eurypterids (1–5) and a phyllopod crustacean (6).

Fig. 1, dorsal aspect of *Eurypterus remipes*, $\times \frac{1}{3}$; 2, same, from the ventral side, female, $\times \frac{1}{3}$; 3, *Hughmilleria socialis*, $\times \frac{1}{2}$; 4, *Eusarcus scorpionis*, $\times \frac{1}{3}$; 5, *Pterygotus buffaloensis*, $\times \frac{1}{25}$; 6, *Ceratiocaris*. After Clarke and Ruedemann.

In 1911, in southeastern Alaska in the region of Prince of Wales Island (about 55° to 60° N. Lat.), Kirk noted tillites interbedded with late Niagaran marine strata varying in thickness between 1000 and 1500 feet. The material is morainic and the bowlders are abundantly striated. Interglacial warmer climates also appear to be indicated. It may be that the tillites of Finmarken are likewise of this time (see p. 232). F. P. Shepard also described (1922) what appear to be Silurian tillites 200 to 500 feet thick in the mountains of British Columbia.

Oldest Known American Desert. — In the late Silurian of New York and Ontario many of the strata are red beds and associated with them are gypsum and much salt (see p. 279). In Great Britain, red beds are also present in the closing strata of Silurian time. This evidence indicates that desert conditions prevailed here at this time, and these climatic conditions were even more prevalent and of far wider extent throughout most of the Devonian.

Caledonian Disturbance of Western Europe

No mountains were made in North America during Silurian time. Active volcanoes of the explosive type, however, were common in southern Maine throughout the Middle Silurian, as indicated by thick Silurian deposits which consist almost wholly of ashes. At the same time other volcanoes throughout a great part of Gaspé Peninsula were pouring out vast volumes of lava; at Black Cape the lavas are many hundreds of feet thick and are interbedded with late Middle Silurian limestones.

In Great Britain, toward the close of the Silurian, arose the majestic Caledonian ranges, extending from Ireland and Scotland into far northern Spitzbergen. This was one of the most important times in the geologic building of the British Isles, and Jukes-Browne states that the Caledonian ranges must have been much grander and loftier than the Alps. The significance of the Caledonian movement is best seen, however, in Norway and Sweden, where the pre-Devonian strata over an area 1100 miles long have been overturned and pushed horizontally eastward some tens of miles.

In 1910 it was held that the major thrust in the north of Norway was at least 86 miles. Recently, however, Holtedahl (1921) has brought together the newer work and it appears that the overthrusted masses of Cambrian, Ordovician, and Silurian ages, intruded by granite and gabbro that rose into the sedimentaries while they were in motion, now have, due to pressure from the north, a typical imbricated structure. These orogenic movements, he states, were of long duration. In southern Norway the overthrustings were seemingly not greater than

from 10 to 20 miles, but in the north in the zone of present high mountains they were probably considerably greater. The thickness of the moved mass is at present less than a mile, but originally it must have been much greater. On the other hand, it appears almost certain that the Scandinavian countries have for a long time lain at a low level in respect to that of the sea, and great parts of southern Norway and Sweden were again invaded by it in late Cretaceous time. The present mountainous character of Norway is undoubtedly due to deformation in late Cenozoic time, an elevation that must have been a few thousand feet higher then than now, as proved by the deeply submerged marginal valleys, the beautiful fiords of Norway.

Other ranges trending from northwest to southeast also came into being in France at this time, extending from the Ardennes through the Taunus and Thüringerwald of Germany into Moravia, beyond which they are hidden by the later overthrustings of the Carpathians.

"In Asia the margins of the old Irkutsk basin of Siberia were folded into a semicircular mountain chain, while a new geosyncline came into existence in what was formerly a part of the oldland, and in this the succeeding marine strata were deposited" (Grabau 1921).

New mountains were elevated late in the Silurian in the Sahara desert, for the nearly horizontal Lower Devonian strata rest unconformably upon the folded Silurian beds of the Oran Sahara. Finally, for the second time, much of eastern Australia was folded into mountains. In South America there also must have been much mountain making in late Silurian time, since these strata are absent here, and the following Lower Devonian coarse and muddy marine deposits are in thick formations and of very wide distribution in the Andes and the lowlands to the east.

Close of the Early Paleozoic. — The making of mountains in several continents toward the close of the Silurian, along with the first common appearance in the Devonian of fresh- and salt-water fishes and land floras, is taken as the basis for delimiting the early Paleozoic subera. The early Paleozoic is therefore characterized by the dominance of marine life and the scarcity of living things upon the dry lands and in their fresh waters. The account of the later Paleozoic will bring out the peopling of the lands by the rising land floras and faunas.

Economic Products

Clinton Fossiliferous Iron-ore. — In the Clinton formation of the Appalachic trough from New York to Alabama, there occur in many regions one or more beds, varying from a few inches to 10 and even 40 feet in thickness, of regularly stratified, argillaceous, red iron-ore or hematite (Fe_2O_3). They contain from 30 to 50 per cent of iron and were formerly mined throughout the Appalachian

Mountains, but now are worked extensively only in the Birmingham region (Red Mountain) of Alabama. The ore is usually more or less cross-bedded, fossiliferous, and made up of clay, some sand, oölites, and the fragments of invertebrate animals, the calcium carbonate of which is now more or less replaced by ferric oxide; the deposits are, therefore, often called " red fossil ore." The beds were evidently made in storm-beaten shallow seas where trituration or breakage of the shells was marked, with a loss of the carbonic acid. Frequently, the grain of the ore is oölitic and cross-bedded or the

Fig. 90. — Sun-cracked impure Silurian limestone (Salina). Natural cement rock. Round Top, Maryland.

particles are flattened like flaxseed, and accordingly the ores are also spoken of as oölitic and flaxseed iron ores. In Tennessee, they are known as the Dyestone ores. It is said that over 600,000,000 tons of these oölitic iron-ores are still available under ground.

Silurian Salt in New York. — The Salina deposits (see table, page 264) of central New York, southern Michigan, and Ontario, are one of the very important sources of salt in the United States. The salt is obtained by deep mining of rock salt, or by underground solution, the water being forced down through one driven hole and pumped out of another, and the brine evaporated by artificial heat or that of the sun and air.

The Salina formation of New York consists mainly of reddish shales with some thin bands of dolomite. Its outcrops extend as a narrow belt across New York State from the Helderberg Mountains westward to Niagara Falls, where the thickness is 380 feet in well borings. From this belt the strata dip southward beneath the younger formations, and 25 miles nearly south of the Batavia outcrops they are 1000 feet beneath the surface, and 1500 feet at a distance of 33 miles. At Syracuse the thickness of the formation is about 600 feet, at Ithaca 1230 feet. Salt springs occur in many parts of New York west of Syracuse and Tully. Rock salt occurs in New York at depths of 800 to 3000 feet or more, over an area measuring 150 miles from east to west, and 60 to 65 miles in width if regarded as extending only to the Pennsylvania boundary. The northern limit of the area is near Morrisville, where 12 feet of salt were found, and near Leroy, 100 miles west of Syracuse, where a bed 40 feet thick exists. In Livingston and Wyoming counties the salt beds have an aggregate thickness of 50 to 100 feet, some beds of pure salt being 40 to 80 feet thick. At Ithaca the seven beds of salt have together a thickness of 250 feet and they alternate with shale between depths of 1900 and 3130 feet. For distribution see Map 4, p. 273.

Glass Sand. — In Pennsylvania and Maryland, a white, clean, hard sandstone of angular quartz grains, the basal member of the Alexandrian series (Tuscarora sandstone), is much quarried and crushed for glass sands and abrasives. In northwestern Ohio and southern Michigan the Sylvania quartz sandstone, attaining to a thickness of 150 feet, is even cleaner, and is composed of rounded grain sands, the wind-blown sands of a Silurian desert. This is an ideal material for the making of glass.

Cement Rock. — The Upper Silurian of the Appalachian area, central and western New York, Ohio, Indiana, Michigan, and Ontario, abounds in dark blue, laminated and often wonderfully sun-cracked, impure magnesian limestones, known as water-limes (see Fig., p. 279). These natural cement rocks were at one time widely used for the making of Portland cement, but have now almost everywhere been superseded by pure limestones of Champlainian age, which can be mixed with clay to any desired percentage, according to the quality of cement wanted. See Champlainian chapter, p. 245.

Collateral Reading

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CHAPTER XXII

CORALS AND CORAL-LIKE ANIMALS

General Description. — In the present shallow seas and oceans, and more especially in the warm-water ones, there is a great variety of radially symmetrical animals, with or without external skeletons of horny or calcareous materials. These flower-like animals are

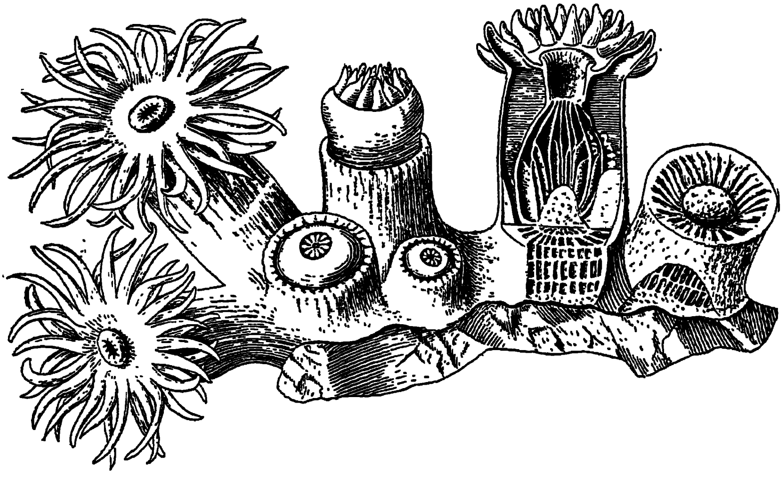

Fig. 91. — Colony of living stony corals, with two individuals fully expanded and feeding, and three individuals retracted and resting. On the extreme right is seen the skeleton of an individual and beside it another one cut through the center to show the relation of the soft parts to the skeleton, the mouth opening into the gullet, and the large digestive cavity with its many mesenteries. After Pfurtscheller, from Boas's *Lehrbuch der Zoölogie.*

the corals and anemones, technically known as the *Cœlenterata,* the name implying that they are sac-like, having but one internal cavity which serves both as a body cavity (cœloma, characteristic of all higher animals) and as a digestive sac (enteron). This simple body structure, comparable to a double-walled sac, has the mouth end frayed out into tentacles, while the other end is attached to foreign objects on the sea bottom.

The cœlenterates are, as a rule, very simple animals in which appear the beginnings of definite organs. In their variety they seem nearly

to exhaust the possibilities of radial symmetry, and many are very flower-like. They have therefore also been called zoöphytes (plant-animals), and their budded colonies afford interesting illustrations of coöperation and division of labor. Some, like the anemones, do not secrete a skeleton, but a great many other kinds do, and all such are commonly spoken of as stony corals, but all coral-like calcareous skeletons are by no means the work of true corals.

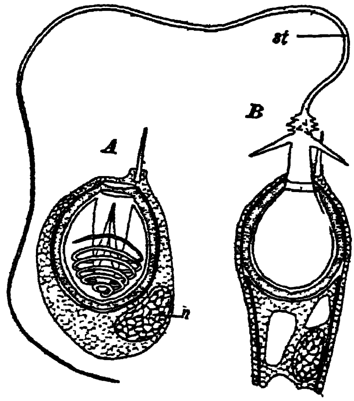

Fig. 92. — Stinging or nettle cells of *Hydra*. Greatly enlarged. After Schneider. *A*, undischarged cell, note trigger hair. *B*, discharged cell with the poisonous thread (*st*) released. *n*, nucleus.

The cœlenterates sting to death the larger animals on which they feed. This stinging is done by a multitude of very minute threads, each one of which is shot out of a cell buried in the skin and enters any soft body that comes into contact with the animals (Fig., opposite).

Into the mouth is passed the food, which is digested in a more or less simply constructed cavity of the sac, and through the same opening is ejected any indigestible remainder. They feed, as a rule, on the smaller animals, but when the individuals, or polyps, as they are called, are minute, their food consists of microscopic animals or plants.


Fig. 93. — A sea anemone, with tufts of tentacles about central mouth. After Emerton.

Anthozoa

There are many types of cœlenterates, but in this chapter we are concerned only with the more complicated ones, the rock-making Anthozoa (means flower-animal). These are the stony corals and many of them are reef and rock makers. The animals that build the stony reefs are usually very small (under one fourth of an inch), though some kinds attain a diameter of an inch or more. The colonial skeletons may be of any size up to 15 feet across and in height.

The internal cavity has hanging down in it a rudimentary, tubular, digestive gullet, opening upward into an elongated mouth and below into the true digestive cavity or *cœlenteron* (see Fig., p. 282). The

wall of the latter has a number of longitudinal folds or ingrowths of the body wall projecting more or less deeply into the cavity. When one of these polyps is cut transversely the folds or partitions are seen as radii, for which reason they are also known as ray animals (Fig., p. 282). When a hard supporting skeleton or stony part, known as the *corallum*, is present, as is most often the case, it is usually made of calcium carbonate (see Pt. I, p. 182), is nearly always secreted by the outer layer of the soft body, and has its exact form. Therefore the skeletons of corals have a radiate or partitioned structure, and it is only this lime skeleton which is preserved in the fossils (see Fig., below). The polyps either live singly and are then

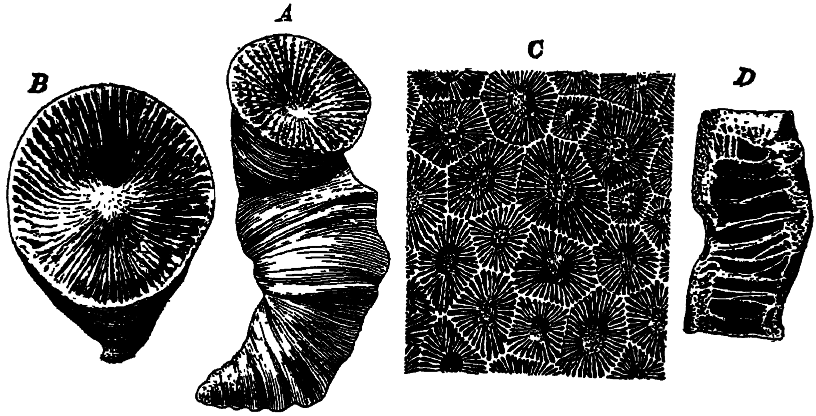

Fig. 94. — Paleozoic Tetracoralla. *A*, common Devonian cup coral (*Heliophyllum halli*); *B*, Silurian cup coral (*Zaphrentis umbonata*), showing the fossula; *C*, a colonial type (*Cyathophyllum rugosum*); *D*, Devonian cup coral, sectioned to show internal tabulæ (*Amplexus yandelli*). After Rominger.

cylindrical or conical in shape (the cup corals), or more commonly form colonies by the budding of closely adjoining individuals.

The Coral Skeleton. — Cup corals, which are the calcareous bases of single polyps, are of very frequent occurrence in Paleozoic rocks. They multiply by sexual reproduction and not by budding, as is the case in colonial forms. Cup corals are usually conical and more or less curved, with variably deep cups divided into many shallow compartments by radially arranged partitions called *septa* (see Fig., above). These septa originate in the outer wall and are of variable length, the several lengths being disposed in a regular manner; only a part of them, the primary septa as a rule, meet in the center, where they often form a simple or twisted column, the *columella*. The colonial corals have about the same general

structure as the single polyps, but when closely crowded the corallites take on a prismatic form (see Fig., p. 284). They may also be circular in outline and then the spaces between the individuals are filled with a loose structure.

The types of coral structure most often seen fossil are the following:

Tabulata or tabulate corals (*tabula* means table and has reference to the many transverse partitions found in the tubes). — These primitive but specialized Paleozoic corals always grow in colonial form and never as single individuals, hence among the Tabulata there are no cup corals. As a rule, the individual polyps are small or even minute transversely, but longitudinally they build more or less long tubes that are abundantly partitioned by tabulæ and perforated by pores as the animals grow upward (see Fig., above). The polyps may be loose in growth when the individual corallites are round or oval in outline, but more often the tubes are tightly appressed to one another and the corallites uniformly prismatic. There are no radial septa and when such appear to be present they are seen to be a series of short spines arranged in longitudinal rows (incipient septa, as it were), or the spines may be irregularly disposed. The Tabulata are therefore Paleozoic corals without true septa, and are thereby readily distinguished from their associates, the Tetracoralla. The walls of the corallites are thin and perforated by large pores, the mural or wall pores (see Fig. *B*, above), which represent failures at budding for the reason that almost no space is present for the vast majority of the possible buds to grow into individuals.

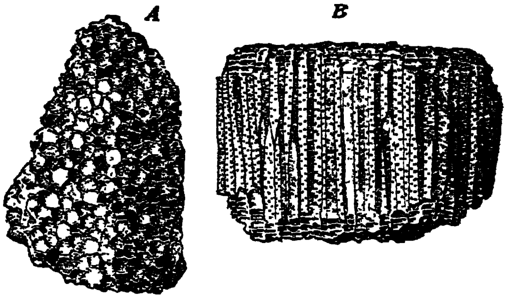

Fig. 95. — Tabulate or honeycomb coral (*Favosites*). *A*, from the top; and *B*, from the side, to show transverse partitions (tabulæ) and small mural pores.

The tabulate corals appeared in the Middle Champlainian and had their greatest development in the Silurian and Devonian. The

chain coral (*Halysites*, Pl., p. 270, Fig. 1) was characteristic of the Silurian and Champlainian, while the honeycomb corals (*Favosites*, Fig., p. 285) were great reef makers in the Silurian and Devonian, where some of the colonies had a diameter of 4 feet. The organpipe-like coral (*Syringopora*, Pl., p. 320, Fig. 8) was common throughout the Silurian and most of later Paleozoic time.

Tetracoralla or tetracorals (corals with the septa arranged in four quadrants or bundles). — Throughout the Paleozoic from Middle Champlainian time, and more especially beginning with the Silurian, the tetracorals are common fossils (see Figs., p. 284, and 4–7, p. 320). They occur as single corallites, the cup corals, or in compound colonies. Cup corals were very common in the Middle Paleozoic and were more numerous, in greater variety, and of larger size (up to 2 feet long) than those of subsequent times. Compound tetracorals were also abundant, and, with the cup corals, were of wide distribution, being especially common as reef makers in the Silurian and Devonian. They were rare in the Pennsylvanian and passed out of existence with the Permian.

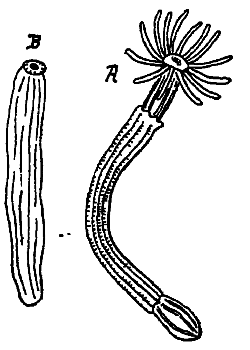

Fig. 96. — *A*, a living, cold-water, burrowing actinian having but eight mesenteries (*Edwardsia beautempsi*), about half natural size. *B*, possibly a related Middle Cambrian form (*Mackenzia costalis*), half natural size. After Raymond.

In the cup tetracorals the bundling of the septa is usually readily seen, and with their smooth or somewhat wrinkled exterior covering (*epitheca*) extending from the base to the edge of the cup, they are easily distinguished from other kinds. The compound tetracorals are usually not so easily separated from the Hexacoralla (six-rayed corals), because the tetramerism or division into four parts is much or wholly obscured, but, as a rule, it is seen that the polyps are larger while the radial septa are more numerous or at least thinner, straighter, and simpler. Some of these compound tetracorals attain the size of modern colonies and have been seen as large as 12 feet across.

The most primitive zoantharian in the seas of the present is *Edwardsia*, and the living Hexacoralla are known to pass through an *Edwardsia*-like stage in their ontogeny. *Edwardsia* is a soft-bodied animal, i. e., devoid of a skeleton, and lives in the colder waters. In the Middle Cambrian near Field, British Columbia, Walcott has found a fossil very like *Edwardsia*, and also without a calcareous skeleton. This he has named *Mackenzia costalis*, regarding it, however, as a holothurian. Raymond suggests that *Mackenzia* may be closely

related to *Edwardsia*, and that similar forms may have given rise in the Champlainian to the lime-secreting Tetracoralla, and later in the Triassic to the stony corals, or Hexacoralla. (See Fig., p. 286.)

Hexacoralla or hexacorals were the common kinds after Paleozoic time and are the main reef builders of the present oceans. The name has reference to the fact that the young polyps start with six primary septa and all subsequent cycles of partitions are regularly introduced between the previous ones. There is, therefore, a regular radial arrangement of the septa and they are never bundled into quadrants as in the Tetracoralla, and the single polyps are also not so decidedly cup- or funnel-shaped. In the compound forms the animals are apt to be small, often very small, as in the staghorn corals, while the corallites are not, as a rule, so distinctly walled from one another as are the older corals. The walls often also appear to be thick, and in many forms the individuals are compressed and seem to merge irregularly into one another, suggesting the convolutions of a mammal brain, hence the name brain-corals, which is sometimes applied to them. See Pt. I, p. 183.

Habitats of Living Corals. — Hexacorals live in all oceans from sea-level down to 11,000 feet, but are particularly common in clear tropical waters and in depths of less than 240 feet. In the deeper, darker, and colder waters the single polyps predominate, while on the reefs where the sunlight is strong the compound corals are most prolific. There are five times as many kinds of hexacorals in waters not over 150 feet deep as there are between this depth and 240 feet, the maximum depth to which any reef species extends. Between 600 and 2400 feet there is another coral zone, usually of small single polyps or of delicate, branching, compound forms. Beyond the latter depth corals are few in number and variety and those that do exist are small and extremely fragile. Off the eastern coast of North America between Cape Hatteras and Newfoundland there are living fourteen species of corals, several of which go below 6000 feet (Verrill). Hemispheric corals are known to attain 15 feet in diameter, while staghorn colonies are reported growing to heights of 15 feet.

In regard to the temperature, strictly reef-building corals flourish only between 68° and 78° F., but will continue to live even at 85° F. The deeper coral zone has a far lower temperature, one between 40° and 50° F., and the deep-sea species may live in water as cold as 32° F. In other words, corals may live at any depth of sea water, but *reef-making* corals live only in warm and shallow waters.

Probably there are more coral reefs to-day than at most times in the history of the earth, even if they are now all restricted to the warmer oceans. It is estimated that about one twentieth of the shelf seas (500,000 square miles) are at present covered with coral reefs. This excess seems to be due to the recent rising of the oceanic level in consequence of the increased water resulting from the melting of the polar ice caps. Through the elevating of the oceanic level the lower areas of the reef corals become more favorable and enlarged habitats. In regard to the nature of coral reefs and their places of growth, see pages 182–190 of Pt. I. For fossil coral reefs, see the Silurian and Devonian chapters.

Collateral Reading

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W. Saville-Kent, The Great Barrier Reef of Australia. 1893.

T. W. Vaughan, Some Shoal-water Corals from Murray Island (Australia), Cocos-Keeling Islands, and Fanning Island. Papers from the Department of Marine Biology, Carnegie Institution of Washington, Vol. 9, 1918, pp. 51–210. (See for fine photographs of living corals and for list of other papers on corals by the same author.)

Paleozoic Corals:

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James Hall, Devonian Fossils, Corals. New York Geological Survey, 1876. Also in Paleontology of New York, Vol. 6, 1887.

P. E. Raymond, The History of Corals and the "Limeless" Oceans. American Journal of Science, 5th series, Vol. 2, 1921, pp. 343–347.

Carl Rominger, Fossil Corals. Michigan Geological Survey, Vol. 3, 1876.

CHAPTER XXIII

THE RISE OF FISHES AND THE PROPHECY OF VERTEBRATE DOMINANCE

In this chapter we are to study the fishes, their kinds, their ancestry, and how their more versatile descendants came to leave their ancestral water habitats for the land. It is a most fascinating study, since all humanity is interested either in the great economic value of fishes, or in the happy hours their pursuit gives the angler, but it has a special interest for the philosopher who sees in the fishes a step on the path of evolution that leads from the wormlike invertebrates to the pinnacle of organic independence in reasoning man.

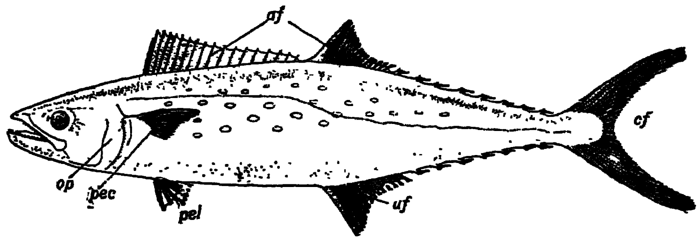

Fig. 97. — Spanish mackerel, a swift-swimming fish, to show external parts. After Goode. *af*, median anal fin; *cf*, caudal or tail fin; *df*, dorsal median fins; *op*, left operculum or movable covering over gills; *pec*, one of the front paired or pectoral fins; *pel*, paired pelvic fins, which may in different fishes be situated anywhere from this position back to a place in front of the anal fin.

Fishes were the first markedly successful class of vertebrates. With the possession of a vertebral column and a central nervous system, and with their greater alertness, mobility, and fecundity, they have an easy preëminence over their invertebrate inferiors. They are as markedly adapted to the water as the birds are to the air. As a rule they live either wholly in the seas and oceans or wholly in the fresh waters of the lands. Many of the marine fishes, however, spend part of their lives in fresh waters; some feed and breed in either fresh or marine habitats; others feed in the sea and breed in the rivers, or in rare cases, like the eels, pass from the rivers out into the sea to breed. Of the marine fishes ascending rivers to breed, some have remained there through choice, others have become "land-locked" through the rising of land barriers, and have evolved

into distinct races or species. Through stream capture and the spreading of fish eggs on the muddied feet of wading birds, the fresh-water fishes have attained their present wide radiation over the continents.

Distinctive Features. — Fishes are vertebrates without a neck. They also have no ears and therefore there is no ear drum present. Their body temperature is about that of the medium in which they live, wherefore they are said to be cold-blooded. Because of their water habitat, all fishes have *gills* and *fins* (see Fig., p. 289). The gills are on each side of the head and consist of delicate, hollow filaments in which the blood circulates. Water is taken in through the mouth and passed out over these breathing organs, where the blood in the tubes extracts the free oxygen dissolved in it. The *mouth* is usually provided with teeth. An *air bladder* is generally present and then may serve as a hydrostatic organ or float, though in certain forms it is modified into a cellular sac, which acts as a lung and assists the gills in respiration.

The skin is either soft and naked, or, more commonly, protected by the development of spines, mosaics of denticles, overlapping *scales*. or bony plates known as scutes. The principal organ of locomotion is the powerful tail. This is assisted by the *paired fins*, of which the forward set, known as the *pectoral limbs*, lie just behind the gills, and the rear pair, or *pelvic limbs*, are placed farther back (see Fig., p. 289). The paired fins of fishes correspond to the fore and hind limbs of the higher vertebrates. Their skeleton, however, cannot be readily compared with the limb structure of other vertebrates. How these fins became limbs is discussed later in this chapter. Fishes also usually possess a variable number of *unpaired median fins* that are used mainly as balancing organs; those on the back are called *dorsal fins*, those on the under side between the anus and tail are known as *anal fins*, and the tail represents a *caudal fin* (see Fig., p. 289). All the fins are supported by skeletal bars or rays, called fin rays.

The skeleton throughout may be of cartilage, though usually it is more or less bony. The main skeleton consists of the *vertebral column*. The bones of the head are of two kinds, dermal or skin bones like the scales, and the actual bones of the brain case.

Types of Fish Tails. — The tail presents three general types. (1) The vertebral column continues in constantly diminishing joints nearly to the end of the animal, and is there surrounded by a symmetrical, one-lobed, vertical tail fin. This is the most primitive type, very common among the Devonian fishes, and seen in the baby stages of most living fishes; it is known as the *diphycercal* or sym-

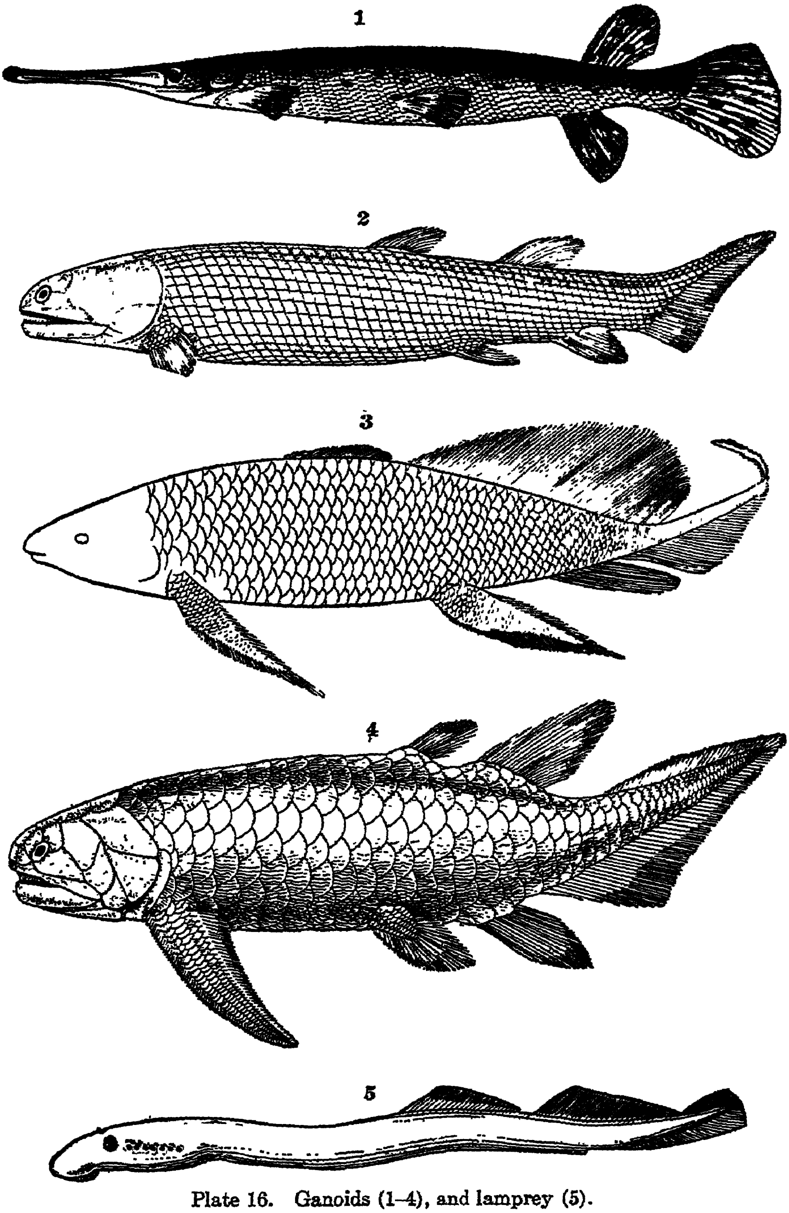

Plate 16. Ganoids (1–4), and lamprey (5).

Fig. 1, living American gar-pike (*Lepidosteus osseus*), $\times \frac{1}{8}$; 2, Devonian ganoid from Scotland (*Osteolepis macrolepidotus*), $\times \frac{1}{3}$; 3, Upper Devonian ganoid from Scaumenac Bay, Canada (*Scaumenacia curta*), $\times \frac{1}{2}$; 4, Devonian ganoid with cycloid scales, from Scotland (*Holoptychius flemingi*), $\times \frac{1}{3}$; 5, living marine lamprey (*Petromyzon marinus*), $\times \frac{1}{8}$, note the seven openings back of the eye, exits from the gills; also edge of circular mouth, and absence of paired fins.

Figs. 2 and 4 after Woodward, British Museum Guide Book; Fig. 3 after Hussakof.

metrical tail (see Pl., p. 295, Fig. 4). (2) In others, the vertebral column bends upward and terminates with diminishing joints in the upper and larger lobe. Hence this type of tail is rarely symmetric, and is called *heterocercal* because of the inequality of the lobes (see Pl., p. 291, Figs. 2, 4; Pl., p. 295, Figs. 1, 2). It is common in living sharks and in most Paleozoic fishes. (3) The modern bony fishes also have a symmetric tail, but while the vertebral column here again bends upward, it ends rather abruptly, and from the terminal joints the fin rays develop in such a way as to form a symmetric tail. This kind of caudal appendage is called *homocercal* (see Fig., below).

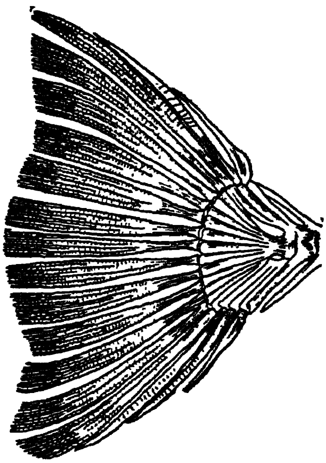

Fig. 98. — Skeleton of the homocercal tail of a flounder.

Food of Fishes. — Among living fishes some feed exclusively on plants, some on plants and animals alike, some exclusively on animals, and others on the mud in which minute plants and animals occur. The majority of fishes, however, feed on other fishes, without much regard to species, devouring their own young as readily as those of any other kind. Teeth with blunt tips usually serve for crushing shells; teeth with serrated edges often signify plant-feeding forms; while strong incisors may indicate the choice of snails and crustaceans as food. In general, the sharper the teeth and the larger the mouth, the more distinctly a species is a fish-eater. Small-mouthed fishes are apt to be plant- or mud-eaters.

Growth. — Fishes grow as long as they live and their size depends upon their ancestry plus the amount of food procurable: the length of life is variable; some exist many years, others are short-lived, and some appear to be annuals.

Ancestry of Fishes. — In spite of the facts that most fishes have bony skeletons and that fish-like animals are known as far back as the Middle Champlainian, their more primitive fossil ancestors are still undiscovered by paleontologists. Nor are the zoölogists able to determine their ancestry among the vast horde of living forms and their embryos. All that the paleontologist can say is that the oldest fossil vertebrates are undoubted fishes, and seemingly of elasmobranch and ostracoderm kinds. Under these circum-

stances, we will leave this matter to future discoveries and go at once to a description of the kinds of fishes.

Classification of Fishes. — For present purposes, fishes may be divided as follows:

Class **Pisces** or true fishes.
  Subclass **Elasmobranchii** or gristle fishes
    Order **Acanthodei** or spinous sharks
    Order **Selachii** or true sharks and rays
  Subclass **Ostracodermi** or aberrant extinct shark
  Subclass **Ganoidei** or enamel-scaled fishes
  Subclass **Teleostei** or bony fishes
  Subclass **Dipnoi** or true lung-fishes
  Subclass **Arthrodira** or armored fishes

Subclass Elasmobranchii or Gristle Fishes

The word Elasmobranchii means *having plate-like gills*, and the group includes the ancient and modern sharks, sawfishes, sea-cats (*Chimæra*), skates, and rays. With few exceptions, the living forms are inhabitants of marine waters (see Pl., p. 295, Fig. 3). They are the most primitive fishes, and very early in the Paleozoic give rise to the higher types.

In most elasmobranchs the mouth is on the under side of the head, but in some it is at the forward end. The internal skeleton is of gristle or is cartilaginous, with more or less calcification. The tail is usually heterocercal. The skin often appears to be naked, but there are always dermal denticles (small pieces) tipped with hard, shining enamel, cored with dentine (phosphate and carbonate of lime with fluoride), and with a bony (phosphate of lime) base sunk in the deeper part of the skin. This type of scale is called *placoid*, and has the same structure as teeth, which originally also developed out of the skin. When the denticles are small and closely set they constitute the so-called *shagreen* (meaning a rough mosaic).

The five gill slits on either side of the body back of the head are, in living cartilaginous fishes, either open or covered by a skin flap, never by a bony operculum as in most other kinds. The median fins are often provided with long, sharp, horny or bony spines, this being particularly true of the dorsal ones. It is these spines and the teeth of sharks that are usually preserved as fossils; unfortunately, however, they give little information as to the general characteristics of the animals.

The brain is enclosed in a solid cartilaginous box or skull without sutures or joints, and in this feature the elasmobranchs differ from

nearly all other fishes (the exception being rarely among ganoids), in which the separate skull bones are easily distinguished. There is no swimming bladder.

The acanthodian or spinous sharks are small and the most primitive of true fishes. They appear in the late Silurian, are particularly common in the Old Red sandstone of Scotland, and rarely exceed a foot in length (see Pl., p. 295, Fig. 1). They are differentiated from the true and most other Paleozoic sharks by their plated skin, in which are embedded small, flattened, closely fitting, bony plates composed of dentine and enamel, and by the further fact that the stout spines are not restricted to the median fins but are also developed in connection with the paired fins. The teeth are small and rather of the pointed type like those of modern sharks. The acanthodian sharks are either directly or indirectly the progenitors of the later sharks and the higher ganoids.

The shell-eating sharks were especially well represented in the later Paleozoic, by two families known as cestracionts and cochliodonts. The first group is now best represented by the Port Jackson shark, which lives off South Australia (see Pl., p. 295, Fig. 3), and is characterized by having two stout dorsal fin spines and, in the deeper parts of the mouth, many blunt and pavement-like teeth adapted for crushing shellfish and crustaceans (therefore also known as the "oyster crusher"). In the cochliodont sharks the individual teeth are fused into two large plates whose upper surface has spirally curved ridges suggesting the spirals of snail shells, the characteristic that gave rise to the family term (see Fig. A, p. 342). It is these hard parts that are so often seen in the later Paleozoic and far less commonly in the Mesozoic; the cochliodonts, however, vanished with the Carboniferous.

The modern sharks are the true Selachii (a Greek term meaning sharks). The order includes the large, active, more or less spindle-shaped sharks, the sawfishes, and the flattened, sluggish, bottom-living rays and skates of the present time and of the Cenozoic and Mesozoic eras. This type of shark with sharp-cutting teeth has been abundant. In the Miocene of South Carolina occur teeth of this type, the largest of which are nearly 6 inches in length (*Carcharodon*), indicating sharks with a length of 60 feet. The living great blue shark attains 40 feet in length.

Geologic Occurrence. — In America the oldest shark remains are small fin spines, apparently of acanthodian kinds (Pl., p. 295, Fig. 1), found in the late Silurian (Cayugan and not Clinton as originally stated) of Pennsylvania. With the Middle Devonian, spines, teeth, and skin denticles of small and large sharks become common. In the Mississippian the shell-feeding forms were highly diversified (see p. 341), but lost their ascendency in the Pennsylvanian and practically vanished with the Paleozoic. The cutting type of tooth so general in living sharks is rare in the Paleozoic, is seen more often in the early Mesozoic, but is not common until Cretaceous time.

Subclass Ostracodermi or Aberrant Sharks

The Ostracodermi are heavily armored, and possibly a group of highly aberrant cartilaginous sharks. The subclass includes the oldest known fishes, beginning in the Middle Champlainian and vanishing in the late Devonian. They represent a line of fish evolu-

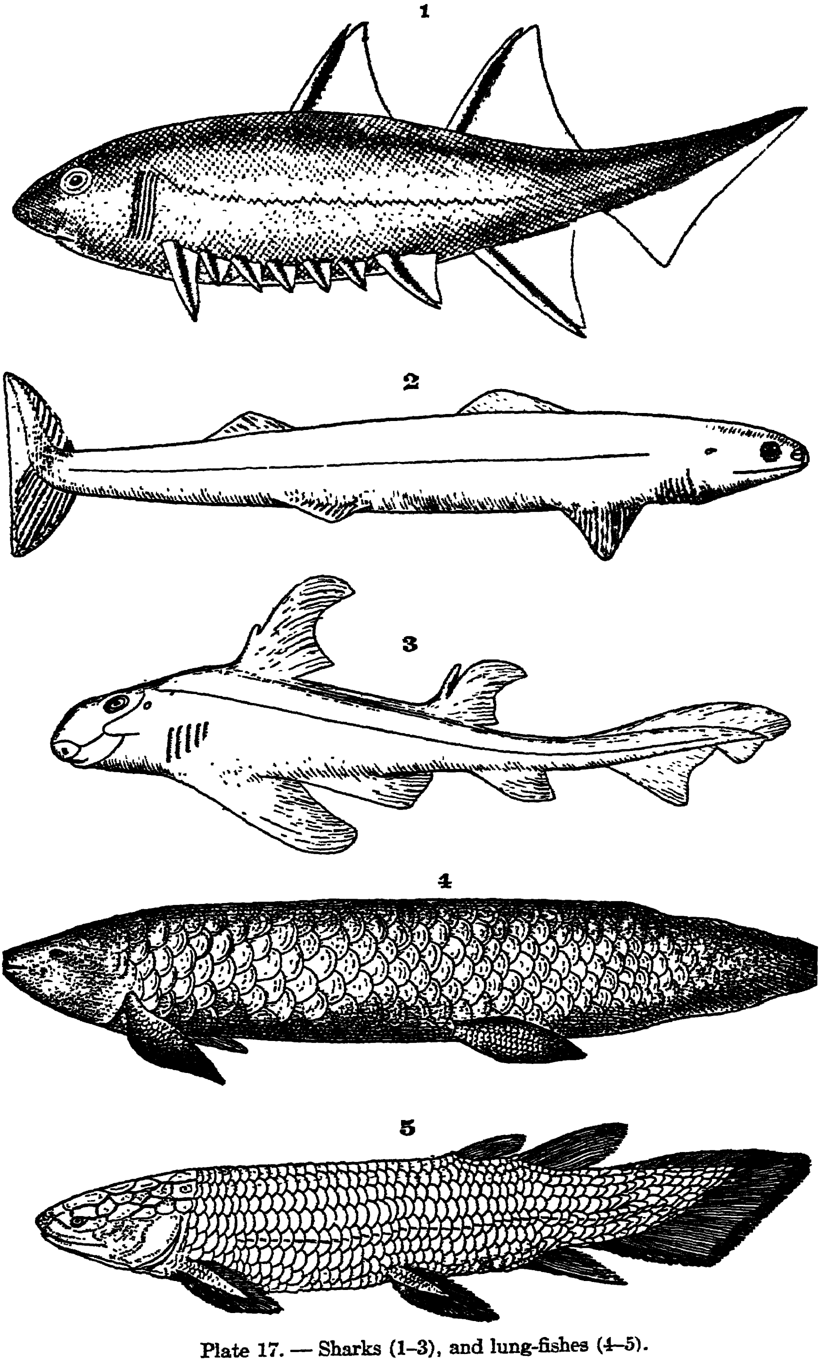

Plate 17. — Sharks (1–3), and lung-fishes (4–5).

Fig. 1, Lower Devonian acanthodian shark, from Scotland (*Climatius macn* *coli*), $\times \frac{1}{2}$; 2, Upper Devonian shark, from Ohio (*Cladoselache fyleri*), $\times \frac{1}{8}$; 3, livin Port Jackson cestraciont shark, from Australia (*Cestracion philippi*) $\times \frac{1}{16}$; 4, livin lung-fish of Australia (*Neoceratodus fosteri*) $\times \frac{1}{11}$; 5, Devonian lung-fish, froı

tion in the wrong direction, for they have left no descendants. They are, in fact, so different from other true fishes as to make it impossible as yet to indicate their relationship to other vertebrates. The ostracoderms were small, none longer than 7 inches, probably bottom-feeders and of sluggish habits, apparently living mainly in the lagoon areas of the seas and in the rivers. The head and anterior body was large, broad, and depressed, and armored by small placoid plates or scales, which were sometimes fused into more or less thick

Fig. 99. — Devonian armored fishes. Below, Ostracodermi (*Pterichthys*), "winged" fishes, with a pair of swimming paddles. Above, marine lung-fish (*Coccosteus*), one of the Arthrodira. After Koken, from Museum Guide of University of Tübingen.

bony plates, while the posterior region was either naked or more or less covered by similar plates or scales. The tail was heterocercal, and there was no internal skeleton (see Figs., above, and p. 297).

In structure and form, there was considerable variety among the bony-skinned fishes. The older kinds, of very diverse construction, were without a pair of lateral paddles or swimming limbs (*Pteraspis, Cephalaspis, Drepanaspis*), and the eyes were either far apart or set closely together (see Fig., p. 297). Restricted to the Upper Devonian occur the forms with anterior armored paddles, decided armor over the anterior region, and eyes closely set (*Bothriolepis, Pterichthys*, once regarded as gigantic beetles, see Fig., above). It is possible, however,

that the latter genera — the "winged fi hes" of Hugh Miller, who remarked that his first impression was that he had found in them "the connecting link between the tortoises and the fish" — do not belong in this subclass. The ostracoderms are widely distributed throughout Europe and North America.

Subclass Ganoidei or Enamel-scaled Fishes

The term Ganoidei, which means *bright appearance*, has reference to the glossy surface of most of these fishes, as, for instance, in the living gar-pikes (see Pl., p. 291, Fig. 1). This glossiness is due

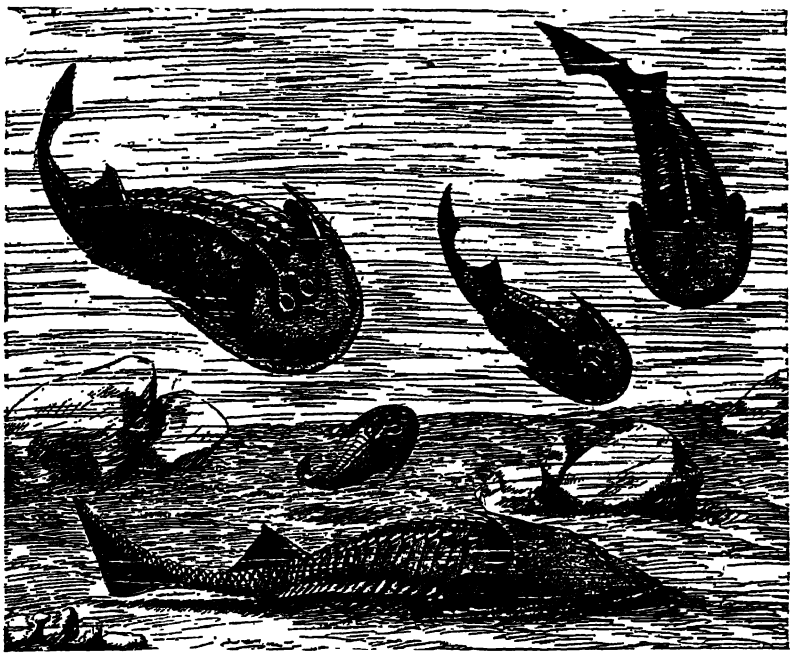

Fig. 100. — Small armored fishes (Ostracodermi) restored (*Cephalaspis*). Lower Devonian of Europe. After Koken, from Museum Guide of University of Tübingen.

to the more or less thick rhombic scales found in gar-pikes or the cycloid scales in Devonian forms, which are covered with bright enamel of the same character as the outer covering in teeth. The ganoid scales differ from the placoid ones of elasmobranchs in that they have but two layers, an outer enamel and a thicker bony layer beneath. In some ganoids, however, there are true elastic cycloid scales, the kind so common in the food fishes, i. e., thin circular plates of phosphate of lime, but without enamel (see Pl., p. 291, Fig. 4). The ganoids are essentially fresh-water fishes, although some are marine and only ascend the rivers to spawn. In the geologic past

the marine members seem to have been considerably more common than now. The best known living examples are the sturgeons and gar-pikes, but the origin of the subclass goes back at least to the Lower Devonian, for they constitute one half the known fish fauna in the Old Red sandstone (see Pl., p. 291, Figs. 2–4) and continue to be abundant until early Cretaceous time. In their organization they form a connecting link between the acanthodian sharks and the bony fishes.

The skull is well protected by dermal bones or is completely ossified, and while the interior skeleton is more or less bony, there are some forms in which it is wholly cartilaginous. In this subclass appears for the first time the perfected fish mouth, in which the lower jaw operates against the teeth of the perfected upper jaw, as in the higher vertebrates. An air bladder is always present and is connected with the gullet; in the gar-pikes it assists in respiration but is never cellular as in the lung-fishes. There is a spiral valve in the intestine, and the tail is heterocercal or diphycercal.

Fringe-finned Ganoids. — According to the character of the fins, the ganoids are divided into two orders, namely (1) the fringe-finned or lobe-finned ganoids (Crossopterygii), and (2) the pillar-finned ganoids (Stylopterygii). In the latter kind the limbs have not the thick, muscular, scale-covered lobes of the other order, but are more like those of the food fishes. Of the first order there are now but two genera, both of which live in the fresh waters of Africa. Even though their air bladder also functions as a lung, these fishes cannot live out of water more than three hours. They were the common fishes in the Lower Devonian, the best known forms being the genera *Holoptychius*, *Eusthenopteron*, and *Osteolepis* (Pl., p. 291, Figs. 2–4). In these ganoids the layers of bone of the conical teeth are often deeply and complexly folded or labyrinthine, and in this are particularly interesting because the same kind of teeth occur in all of the Paleozoic amphibians. This similarity of tooth structure is another hint showing the probable origin of the Amphibia (order Stegocephalia) in these fringe-finned Devonian fresh-water ganoids.

Subclass Dipnoi or True Lung-fishes

The Dipnoi (from the Greek words meaning *double breathing*) are the "lung-fishes," so termed because the three living genera have an air bladder which opens into the mouth and which is either single or double, with numerous cellular spaces. This is an outgrowth of the anterior region of the digestive tract and serves as a lung, supplementing, and in times of drought supplanting, the functions of the gills as organs of respiration. From an evolutionary standpoint, the lung-fishes are very important, because the air bladder is comparable with the lung of the higher vertebrates

in that it returns the aërated blood direct to the heart, whereas in most other fishes the blood is carried from the air bladder through the general circulation before reaching the heart. The nasal sacs are on the exterior of the snout and open into the mouth, a condition met with also in Amphibia and higher vertebrates, but very rarely in fishes. It is in the lung-fishes, then, that we see the possibilities for the development of the higher vertebrates, though this does not necessarily mean that they were the progenitors of the latter. In many ways, they are intermediate in structure between the lower fishes and the amphibious salamanders, but they are not thought to be the direct connecting links between the fishes and the amphibians. It is probable that the fringe-finned ganoids (crossopterygians) were the progenitors of the amphibians.

From the living lung-fishes we learn that certain forms (*Lepidosiren*) inhabit muddy streams and marshes, where they feed on plants. Others feed on worms, insects, shellfish, crustaceans, and frogs. They are sluggish animals, rising occasionally to the surface for a new supply of air; in times of drought, *Lepidosiren* encases itself in a cocoon made of slime and clay, and breathes air through an opening made in the mud. During the rainy season, living lung-fishes eat voraciously, storing up great quantities of fat between the muscles, and this fat sustains them during the dry season, so that they can live without food, sometimes for eight months, until the water returns.

In the living forms there are also either two or four pairs of gills covered by a movable bony operculum. They are generally eel-like in appearance, with the dorsal and ventral median fins usually continuous with the tail fin. Among the Devonian forms the tail is usually of the heterocercal type (Pl., p. 291, Fig. 2), but in recent forms it is diphycercal (Pl., p. 295, Fig. 4). The paired fins are long, broadly lobed, muscular, scaled, and fringed in the Devonian species and in living *Ceratodus*, but in other modern forms they are very slender, pointed, and without the fringe. The body is covered with overlapping cycloid scales.

Dipnoans are cartilaginous fishes in which there is, however, some ossification, but they have no vertebræ differentiated as such. The skull consists of cartilage covered by a variable number of membrane bones that are thickest in Paleozoic genera. These are superficial bones developed in the membrane covering the cartilage, and are not formed in the cartilage itself. The teeth are few in number, usually in three pairs, of which two sets are large crushing plates.

The dipnoans are closely related to the fringe-finned ganoids, these two types of fishes being the most important offshoots of the primitive sharks and evolving toward the higher vertebrates. The oldest dipnoans, in about fifteen species, occur in the Devonian of both Europe and America.

Subclass Arthrodira or Armored Fishes

The most striking fishes of the Devonian seas were the highly armored Arthrodira, almost 40 per cent of all Devonian fishes being of this subclass. The term Arthrodira means *jointed neck,* and is given because the armor of the head slides somewhat over that of the body, thus allowing the head to move up and down, a rare feature among fishes and best developed in this subclass. Arthrodira are more or less heavily armored and in this respect remind us of

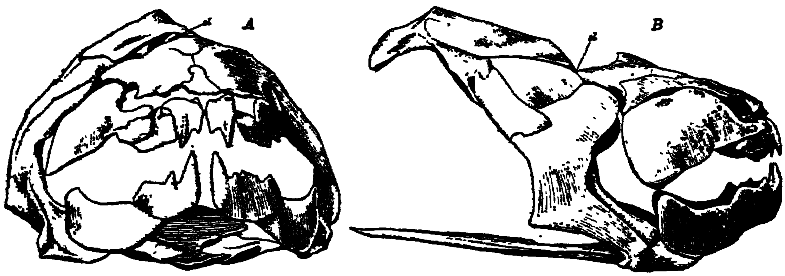

Fig. 101. — The "terrible fish" (*Dinichthys*), an armored arthrodire from the Upper Devonian of Ohio. *sl.* sliding joint, the feature that gave rise to the name Arthrodira. Original in American Museum of Natural History. Also see Fig., p. 296.

the lung-fishes and the earliest amphibians. Their systematic relationship is still unknown, however, but apparently they are nearest the lung-fishes and the fringe-finned ganoids. It is because of this supposed relationship that they are called by A. Smith Woodward large-headed lung-fishes. Of course, nothing is known about the lungs and breathing habits of the Arthrodira.

The oldest arthrodires occur in the early Devonian fresh-water deposits of Germany, while those of the Middle and Upper Devonian of North America were marine. They were the largest and fiercest fishes of this period, but died out in the earliest Mississippian, a time when the shell-feeding sharks rose to the dominancy of the seas.

The arthrodires had no true teeth; the structures functioning as such were large cutting shears or crushing plates. The tail was heterocercal and there appears to have been a pair of pelvic fins.

Of an internal skeleton there was little, for the vertebral axis was not bony, though the neural and ventral arches were somewhat ossified.

The Arthrodira easily dominated the aquatic life of the Devonian seas, one American form, *Dinichthys*, the "terrible fish," attaining a length of over 20 feet (Fig., p. 300). There are more than forty species known in North America, and one locality in Germany (Wildungen) has alone yielded upward of fifty forms.

Subclass Teleostei or Bony Fishes

The teleosts (means *true bone*) are the modern fishes and express the highest organization among these animals, for their evolution has tended to complete adaptation to the water (see Fig., p. 289). They constitute about 99 per cent of all living fishes. Most of the fishes of commerce and sport are of this subclass and occur abundantly in the fresh waters, seas, and oceans. Their origin was in the Ganoidei, apparently in late Paleozoic time, but they were not common until the Lower Cretaceous, with their best development in the Cenozoic and at present.

The bony fishes are nearly always covered with thin, elastic, cycloid scales, never with placoid, and very rarely with ganoid scales. In some the skin is naked and slimy. The caudal fin is usually homocercal and the paired limbs are never lobed. The gills are always covered by a movable operculum. The elongated air or swimming bladder, when present, is filled with gas and lies dorsally to the body cavity; it is not a lung but a hydrostatic organ. The internal skeleton is wholly ossified, the vertebræ are hollow at both ends (amphicœlous), there is a bony neural arch enclosing the spinal nerve-cord, and each vertebra has also a pair of ribs enclosing the viscera. Many of these characters are also seen, but less perfectly, in the Ganoidei, and therefore some naturalists regard both subclasses as representing but a single group.

Origin of Fins and Limbs

Development of Fins. — In the higher marine animals, purposeful locomotion begins through lateral undulating of a flexible body, to which were added *fins* to assist in progression through the water. Fins are of two kinds, the unpaired fin-folds and the paired fins. The originally flexible unpaired fin-folds arose out of the skin and later became rigid, giving the fish a more resistant surface. Such may be more or less continuous from the head along the mid-line of the back (dorsal fin), around the tail (caudal fin), and forward

along the under side as far as the vent (anal fin). It is usual in most fishes to see these unpaired fins discontinuous, that is, localized.

The paired fins, like the unpaired ones, in all probability originated, Lull says, in skin folds, growing out from the two sides of the body, and at first served as keels that gave better balance to the narrow fish body, or checked its forward motion. They are well shown in the acanthodian sharks of the Silurian and Devonian (Pl., p. 295, Fig. 1), and here they were held extended by stout bony spines, just as one sees the dorsal unpaired ones held vertically in modern sharks. In other forms, these lateral bony spines were replaced by internal stiffening rods. Osborn says that in the course

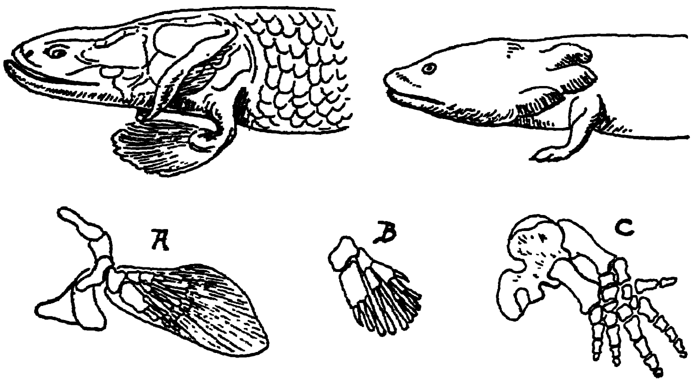

Fig. 102. — Evolution of fins into legs. The upper figures show the theoretic change from fringe-fin (left) to foot of amphibian (right). Below: *A* and *B*, the skeleton of fish fins (crossopterygian); *C*, the skeleton of a foot of a Pennsylvanian amphibian. After Osborn.

of evolution these rods are concentrated to form the central axis of a fully jointed fin, and with further development they transform into the cartilages and bones of the limb girdles (see Fig., above).

In the fishes, the paired fins with their girdles are the rudiments out of which legs and feet were developed through the enforced hobbling about of the fringe-finned ganoids in their search for water holes in desert regions. In them it is thought was developed a structure prophetic of legs and feet, though the actual transitional limb, either in fossil form or in embryos of living limbed vertebrates, is wholly unknown.

The oldest known footprint, *Thinopus* (Fig., p. 331), from the Upper Devonian, may give a hint of what this evolution was like. There appear to be here but two completely formed fingers, probably the first and second, separated

by a cleft that extended deeply into the sole of the foot; the fossil indicates further that a rudimentary third toe was present and possibly even a fourth one. If the structure of this footprint can be relied upon, then the terrestrial foot began with two toes instead of five, as is usually held.

Origin of Double Breathing in Fishes

Breathing Organs of Marine Animals. — A survey of typical marine animals reveals many and diverse methods for the extraction of the free oxygen from the water, but whatever the kind of breathing organ, it is always of the same fundamental type, a localized organ or organs having delicate canals with very thin membranes in which the blood circulates, bringing the red corpuscles into almost direct contact with the surrounding water. The hæmoglobin of these red corpuscles has decided affinity for oxygen, which it extracts from the water and which the floating cells carry through the circulation of the blood to all parts of the animal's body. Nowhere in the sea has any animal an additional organ for the extraction of oxygen directly from the air, excepting in such stocks as are known to have had land-living ancestors.

Evolution of Lungs. — There is in most fishes above the sharks an organ known as the air or swimming bladder, which is structurally a sac-like outgrowth, single or paired, of the alimentary canal. The principal function of this degenerate and secondarily modified structure in most living fishes is that of a hydrostatic organ, to give buoyancy to the animals, and it is controlled by muscles in such a way as to permit its possessor to remain at any desired level in the water. The air bladder is the homologue of the lungs of the terrestrial vertebrates, and is utilized by the so-called lung-fishes, and to a limited extent by other relic fishes (*Amia, Lepidosteus, Polypterus*) as a respiratory organ supplementary to the gills.

The great range of modification of this structure shows it to be of extremely ancient origin, and its incipient condition is possibly shown by a pair of pouch-like outgrowths of the pharynx, or throat cavity, in the sharks. Stagnation of the water and a loss of free oxygen would bring the fishes to the surface to gulp down air, and such pouches, if supplied with blood-vessels, would serve in a very rudimentary way to aid in aërating the blood. A premium placed upon such structures would, it is thought, stimulate their development to the condition seen in the modern lung-fishes.

Origin of Lungs in Animals Living in Temporary Bodies of Water. — Animals originating and living in permanent bodies of

water, and especially in the ocean, have no need to breathe the air, and it is therefore held that the stimulus for such an alteration could have arisen only where the water periodically failed the animals. No fish permanently breathing air is known to inhabit the region between low and high tides, though several kinds live here for a time in search of food. On the other hand, in none of the marine deltas of the present does one find the climatic conditions necessary to force fishes to develop into lung-fishes, nor do they occur in the areas of the strand-lines or in the courses of the permanent rivers. Nowhere is there in these places a transition zone forcing the water-living fishes to adapt themselves to the dry land.

Just as we have arid regions to-day, so it appears that similar land climates existed during much of geologic time. Under such climates, bodies of water come and go according to the season of rain and drought, and hence various methods are resorted to by the animals to maintain their kind or themselves over the period of drought. During the arid season the struggle for existence is severe, not only because of the abnormal crowding of the individuals into constantly diminishing spaces and the reduction in the amount of available food, but even more so because of the increasingly saline and bitter character of the water. It is thought that under the stimulus of these changes gill-breathing fishes first adapted themselves to burrowing in the sand. Thus protected in water and mud holes there was for a time moisture to pass over the gills, but under such environments life was very precarious and in the struggle most of the individuals were destroyed. After innumerable failures in their efforts to gulp the air into the pharynx, efforts lasting through long geologic time, the ganoids and lung-fishes were gradually developed and perfected, their first appearance being in earliest Devonian time.

Highest Mentality among Land-living Vertebrates. — Air breathing, once established among the fishes, has resulted in the land vertebrates attaining the highest mechanical and mental perfection, an evolution necessitated by adaptation to a wide range of environmental conditions as compared with the relative uniformity of the sea. The greatest mentality in the sea has been repeatedly derived from the continents, in that many stocks of land vertebrates have adapted themselves to the sea because of the ease with which they can there prey upon the less alert and intelligent. Out of such stocks, however, comes no higher mentality. They represent an adaptation in the wrong direction, that is, to an easier life, for the highest mentality has been developed only on the land where

the struggle for existence is greatest because of the constant necessity of adaptation to changing environment. Organic supremacy is attained only through constant vigilance.

Collateral Reading

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CHAPTER XXIV

DEVONIAN TIME AND THE DOMINANCE OF THE FISHES

History of the Term Devonian. — Previous to 1833 the geologic column was not determined beneath the "Carboniferous," the time of the world's greatest coal making. In western Europe, however, it was soon noted that above the coal-bearing strata there lay a great mass of red sandstones and marls, and that beneath the Carboniferous in Scotland occurred a similar series. Because geologists had not yet recognized the importance of designating type areas of strata by the name of the locality in which they occur, these two divisions came to be known simply as the New Red sandstone (upper series) and the Old Red sandstone (lower series), with the Carboniferous between them. The Old Red sandstone to this day has failed to yield undoubted marine fossils, and since the geologic column is essentially based on a marine faunal sequence, this lower series did not bear in itself the evidence for correlating it with marine beds. However, not far away from the Old Red area of Scotland, in Devonshire, southwestern England, there had been collected a number of fossil corals; these were placed in the hands of Lonsdale, and he, in 1837, expressed the opinion that they were intermediate in character between those of the Silurian and the Carboniferous, and, further, that the limestones of Devonshire were of the age of the Old Red sandstone.

This important information was imparted in the same year to both Murchison and Sedgwick, geologists to whom we owe, as has been said in earlier chapters, the first determination of the actual sequence of the Paleozoic strata beneath the Carboniferous. In 1839 these two workers concluded that certain of the marine strata of Devonshire were in all probability the equivalent of the Old Red, and that they occupied a stratigraphic position between the Silurian and the Carboniferous, so, fearing that the New York state geologists would soon propose a period name for equivalent formations, they hastened their work, and in the same year defined the period term Devonian. In the type area in southwestern England to this day the base of these rocks is not to be seen, and

a worse region for the erection of a period term could hardly have been selected. The Devonian here was seen eventually to consist of an immense series, 10,000 to 12,000 feet thick, of graywacke, slate, and limestone, with intercalated eruptives and beds of tuffs. All these are decidedly folded and very much faulted, so that the stratigraphic sequence could only be made out on the basis of the equivalent strata of the continent of Europe. This inherent difficulty was soon recognized by Sedgwick and Murchison, and they crossed the channel and began work in the Rhine valley of Germany, where there is one of the best known developments of Devonian faunas. Their results on this area were published in 1842, but although nearly all the strata studied by them are now recognized as Devonian, at that time they referred most of the rocks to the Cambrian and Silurian. In practice, all Devonian correlations are still made with the Rhine area, although the period name is based on the sequence in Devonshire. If our English cousins had waited until 1842, this period would now be called Erian, and the state of New York would be the type area, than which there could have been no better, even in Germany.

Significant Things about the Devonian Period. — There is no more significant or picturesque period in the history of the earth than the Devonian. This is the time when the former nakedness of the lands becomes clothed with a deeper verdure and the first forests appear, providing the needed homes and food for the invasion of the continents by the ever-hungry descendants of the denizens of the sea. The conquest is first attained by the invertebrates — the scorpions, shellfish, worms, and thousand-legs.

The invasion of the land is fairly under way in the Devonian, chiefly in the rivers and lakes, but due to the wide-spread arid climates a fierce struggle is instituted among the inhabitants of the then temporary waters, resulting in the dominancy of the better equipped air-breathing fishes, an issue prophetic of vertebrate ascendency, hereafter never to be questioned in its onward sweep to its culmination in man.

A striking feature of the southern Devonian epeiric seas is their shrinkage along with the closure of the entrance of the Gulf of Mexico during late Middle and all of Upper Devonian times. This withdrawal can not, however, mean a high uplift of southern Appalachis, since in these southern (now cul-de-sac) seas the deposits are thin and nearly always of black muds almost devoid of life; besides, the seas reënter here in the following period.

The strata making up the Devonian system in North America have a very wide distribution, especially those of the Middle Devonian, the Lower Devonian rocks being largely restricted to the Appalachic and Cordilleric geosynclines (see Pl., p. 313). Because of this distribution, the Devonian strata of the interior of the continent are, by their faunal content, readily distinguished in the field from the Silurian, but their separation from the Carboniferous above in the Mississippi valley is not so easy. In this interior region the strata are all conformable upon one another, and the disconform-

Fig. 103. — Quarry face in the Bennett quarries, North Buffalo, N. Y. At the top are cherty limestones (Onondaga) resting disconformably on the Upper Silurian (Cobleskill). Below the second break is the thin series of cement rock (Bertie) reaching to the floor of the quarry.

ities separating the systems can, as a rule, be determined only by the aid of the faunas (see Fig., above). In the Ohio and Mississippi valleys also the Devonian often terminates in a black shale series and the Mississippian system as often begins with a very similar formation (see Fig., p. 183). Almost nowhere are there angular unconformities between them.

The Devonian system in New York is the best known and is therefore the standard for reference in correlation in North America. It is divided as follows:

TABLE OF NEW YORK DEVONIAN FORMATIONS

Complete emergence of North America

Upper Devonian	Bradfordian	Catskill	Hayfield, Cussewago Upper Chagrin, Venango, Salamanca, Warren
	Chautauquan	Catskill	Lower Chagrin, Chemung Portage, Wellsburg, Gowanda, Dunkirk
	Senecan		Huron, Wiscoy, Nunda, Gardeau Naples, Ithaca, Oneonta Genesee, Tully

Great spread of Arctic waters and marked changes in the geography of lands and seas

Middle Devonian	Erian	Hamilton group
	Ulsterian	Marcellus-Onondaga group Schoharie-Esopus group

Beginning of wide oceanic transgression of North America

Lower Devonian	Oriskanian	Oriskany-Port Ewen group
	Helderbergian	Becraft-New Scotland-Coeymans-Manlius group

Small oscillating seas
Complete transition with Silurian in Appalachic trough

American Devonian

Appalachian Area. — The longest sequence and the thickest series of Devonian deposits occur in the northern Appalachian area, where most of the materials are shales and fine-grained sandstones. The Catskills on the west side of the Hudson River are the most imposing single Devonian pile in the United States. The greatest thickness is in Pennsylvania, where the Susquehanna River has cut through the Appalachian Mountains (Fig., p. 310); here the Pennsylvania Geological Survey has determined a maximum depth of nearly 13,000 feet of Devonian shales and sandstones, becoming increasingly coarser, redder, less marine, and more rapid in accumulation with the progress of time, that is, toward the top.

To make more evident what is represented in Pennsylvania, some of the details of the section should be given. In this great series there are from 260 to 425 (Helderbergian 50–100, Oriskanian 210–325) feet of Lower Devonian limestone and arenaceous sandstone. The Middle Devonian starts with the widely spread Onondaga limestone, which has a depth of 0 to 250 feet. Then begins the great detrital series of muds and sands, as follows: Hamilton, 1400 to 2500 feet; Portage, 1100 to 1400 feet; Chemung, 2200 to 4600 feet; and Catskill, 2500 to 3700 feet. In other words, the Lower Devonian has 260 to 425 feet, the Middle Devonian 1400 to 2750 feet, and the Upper Devonian 5800 to 9700 feet, with most of it red shales and coarse sandstones and conglomerates. The thicknesses in Maryland are: Lower Devonian, 340 to 767 feet; Middle Devonian, 600 to 1650 feet; Upper Devonian, 4600 to 8550 feet.

Appalachian Delta. — Along with the greater rapidity of accumulation the marine faunas become increasingly scarcer upward in the section, and the sediments change in character to red beds, most of which are of fresh-water origin, marked by ripples, suncracks, and rain imprints, and have land plants and fresh-water fishes. Pennsylvania was the central area of a great delta formed at the mouth of the large rivers that flowed out of the highlands to the east and northeast, in which latter region there was mountain making

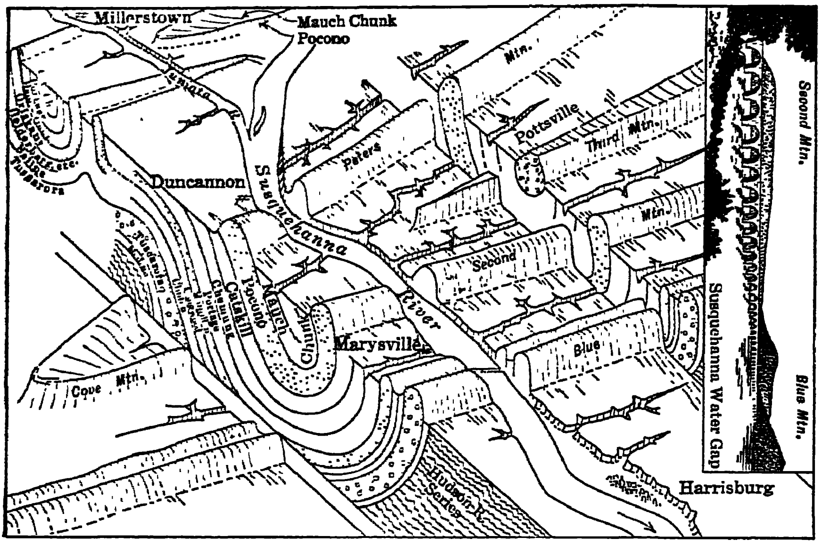

Fig. 104. — Block diagram of the folded Appalachian Mountains, and their geologic structure beneath the ground, to the northwest of Harrisburg, Penn. The inset shows the topography from south of the stone Pennsylvania Railroad bridge over the Susquehanna River looking northeast. The strata shown in this region range from the Champlainian to the top of the Tennesseian. Note that the Susquehanna River flows directly across the strike of the mountains, and that the Silurian (Tuscarora) sandstone makes the crest of Blue Mt., and the Mississippian (Pocono) sandstone that of the second or Peters Mt. The present crests of the mountains are the eroded remnants of the Cretaceous peneplain. After A. K. Lobeck.

and volcanic activity throughout much of the time of the delta accumulation. From this central and rapidly subsiding delta, the deposits thin rapidly to the north west, and south (see map, p. 311).

Devonian Sediments of the Interior. — In the region of the Cincinnati uplift and throughout the Mississippi valley the essentially calcareous deposits, mainly of Middle Devonian time, are very thin when compared with those of the Appalachian region. At Louisville, Kentucky, there is about 60 feet of Middle De-

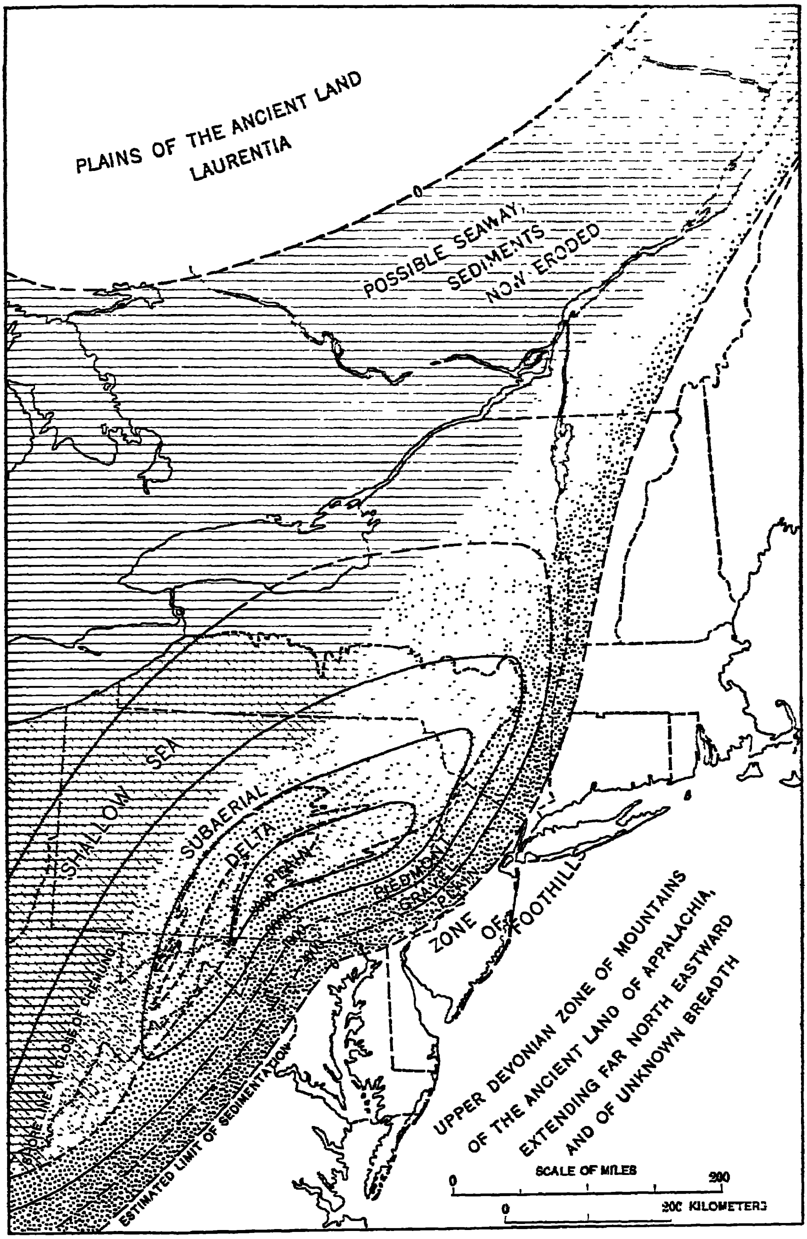

Fig. 105. — Devonian delta of the Appalachic geosyncline, as it probably was at the close of this period. Dotted area that of the fresh-water and brackish-water deposits; horizontal lines, marine deposits. Diagonal lines, the area where the deposits still exist. Contours showing original thickness of Upper Devonian sediments. Drawn by Barrell.

vonian limestone, and 100 feet of Upper Devonian shales, and from here northward, both to the east and west, the sections thicken and introduce more shale, so that in western Ontario there is a depth of about 600 feet, much of which is shale. To the northwest, about Alpena, Michigan, the Middle and Upper Devonian sediments are still thicker, and there are here the greatest accumulations in the medial portion of North America.

In the southern Mississippi valley and in Oklahoma the Devonian sections are thin, and most of the deposits are of Lower and early Middle Devonian time. Probably no single section exceeds 250 feet.

Devonian Sediments of the Western and Arctic Regions. — In the Cordilleric sea the Devonian sediments were essentially limestones, and while the sections within the United States are usually less than 300 feet thick, yet in the Eureka district of Nevada there are from 4000 to 6000 feet of Devonian limestones and calcareous shales. The latter strata seem to represent an unbroken series from the beginning almost to the close of the Devonian period. In Manitoba there are about 400 feet of dolomites, limestones, and shales, and in the Mackenzie valley

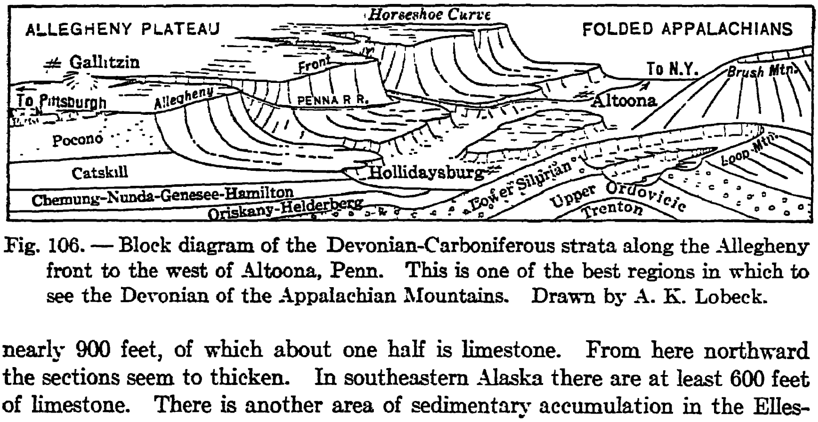

Fig. 106. — Block diagram of the Devonian-Carboniferous strata along the Allegheny front to the west of Altoona, Penn. This is one of the best regions in which to see the Devonian of the Appalachian Mountains. Drawn by A. K. Lobeck.

nearly 900 feet, of which about one half is limestone. From here northward the sections seem to thicken. In southeastern Alaska there are at least 600 feet of limestone. There is another area of sedimentary accumulation in the Ellesmere-Parry Island area, where Per Schei has published a Siluro-Devonian section with a thickness of 8000 feet, most of which consists of coarse Devonian detritals.

Devonian Localities. — The Devonian strata may be seen to good advantage in the Catskill Mountains of eastern New York, and for 25 miles west of Buffalo along the shore of Lake Erie in the western end of the same state (see Fig., p. 308). About Cumberland, Maryland, almost the entire New York sequence is repeated. Cleveland, Ohio, stands on Upper Devonian, and Sandusky and Columbus, also in that state, on Middle Devonian deposits. Louisville, Kentucky, is famous for its Middle Devonian coral reef. Milwaukee, Wisconsin, and Davenport, Iowa, are good places for fossils of this period. In Michigan, at the summer resort Petoskey, and more especially at Alpena, and in western Ontario about Thedford may be found especially fine Middle Devonian organisms.

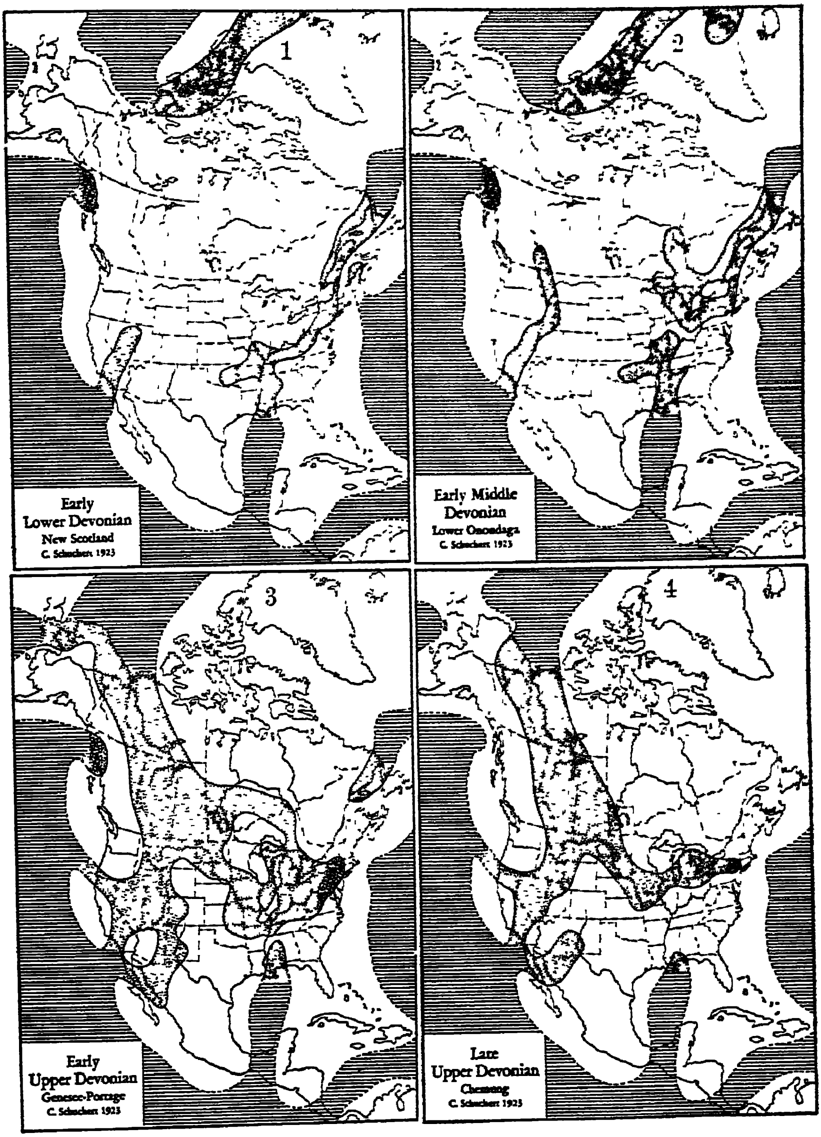

Plate 18. — Paleogeography of Devonian time.

Epeiric seas dotted; oceans ruled. See Plate 19 (p. 317) for late Middle Devonian physiography.

In Devonian time there was but one slowly developing flood, coming from the Arctic Ocean with Euro-Asiatic faunas and attaining maximum spread as depicted in Plate 19 and Map 3 of this plate, with slow recession in Map 4. Note in Map 3 the vast Appalachian delta and the much smaller one of Gaspé, Quebec; also the final absence of seas in the southeastern states.

Another fine Devonian section occurs at Gaspé on the end of the peninsula bordering the St. Lawrence River on the south, where the basal 2000 feet of limestone, of Lower Devonian time, are followed by 7000 feet of Middle and Upper Devonian sandstones. These are the deposits of another large delta. Elsewhere in the Maritime Provinces of Canada and in the New England States, the Devonian is poorly represented, and when present usually consists of continental deposits.

Submergences of the Continent. — At the beginning of Devonian time almost all of North America had emerged, and at no time during the Lower Devonian was more than 10 per cent of the continent covered with marine waters (see Pl., p. 313). These Devonian seas were long and narrow in the Appalachic, St. Lawrencic, and Cordilleric geosynclines, and the waters of the Appalachic trough appear to have been oscillatory and unstable in areal extent.

Late in Oriskanian time the submergence became markedly positive, and attained its maximum flood in the late Middle Devonian (Hamilton), when at least 38 per cent of North America was covered by the sea (see Pl., p. 317). The waters were warm, for they brought from the Gulf of Mexico and the North Atlantic many coral species which built extensive reefs seen in many places in the limestone deposits. Later there was also an Arctic invasion through the Cordilleric sea, and it likewise brought an abundance of corals, this being particularly true for Alaska and the Mackenzie valley.

Probable Cause of Submergences. — The great Middle Devonian flood was also common to Europe, Asia, South America, and Australia, the strata in New South Wales alone having a thickness of 10,000 feet. It was one of the greatest of continental inundations, exceeded later only by the great flood of Cretaceous time. Such a flooding of the lands could not have been wholly due to the unloading of the eroded land materials into the oceans, for it was of too great an areal extent. Previously, however, when discussing the Caledonian Disturbance of Silurian time, it was stated that Laurentis and Baltis were welded into one continent by that movement, and it is probable that the shallow pre-Devonian sea lying between Britain, Norway, and Greenland was also destroyed at that time. It is true that this elevation began toward the close of the Silurian, but that it continued into Devonian time is attested by the marked and long-enduring volcanic activity in Acadis and western Europe. Not only this, but the extremely thick deposits of the Old Red, to be described later, were accumu-

lated in mountain valleys during and immediately after this upheaval, and are further evidence to the same end. Therefore, the displacing of the Norwegian sea by an extensive land area, combined with the unloading of the mountains into the oceans, appears to have caused the general water level to rise everywhere and thus to have brought about the marked inundation of the continents in Devonian time.

Emergence of the Continent. — During the Upper Devonian the seas were gradually withdrawn, first in the southern Mississippi valley and finally throughout the interior of the continent and the Cordilleran area. If there was any water left on the land, geologists have as yet failed to discern its transition strata between the Devonian and the Mississippian. Thus nature delimited another geologic period in the history of the earth, and at the close of the Devonian nearly all of North America was again emergent.

Fig. 107. — Sir William Dawson (1820–1899). One of the founders of Canadian Geology.

The Great Northern Transverse Continent Eris. — We have seen that the Caledonian Disturbance resulted in the making of mountains that extended throughout northwestern Europe. It was then that Laurentis (Canadian Shield-Greenland) was welded upon Baltis (Sweden-Finland), forming the most western part of the great northern transverse land mass that extended unbroken far into Asia. Therefore, at the very beginning of Devonian time there came into existence an almost circumpolar land, whose only submerged portion lay in the North Pacific, and which was formed by the union of Laurentis, Baltis, and Angaris (see Fig., p. 431). The great Canadian geologist, Sir William Dawson, of McGill University, labored long to make known the plant life of the Devonian, and since he termed it the Erian flora after the Erian rocks in which it is entombed, taking the name from Lake Erie and the Erie division of the New York state geologists, Suess in 1909 gave the continent the name of *Eria* (here

changed to *Eris*). It is the ancestral continent of the modern Holarctic region of the zoölogists.

Acadian Disturbance. — The Acadian land, throughout the New England States and the Maritime Provinces of Canada, began to be moved, that is, elevated and folded, in Middle Devonian time, and the sea was finally completely in retreat throughout the entire area, destroying forever the seaways that formerly connected the Central Interior sea with the St. Lawrencic trough. This mountain-making movement, first described by Dawson, was in 1895 named by H. S. Williams the Acadian Revolution; the movement continued to the end of Devonian time, since even the Upper Devonian strata of continental character are folded. Throughout the Devonian, and especially in the Upper Devonian, volcanic activity occurred here on a large scale, many of the lavas and intruded granites being preserved in the Maritime Provinces. The volcanic cones are now eroded away, and what is left are the deeper seated volcanic necks, seen to-day in Mt. Royal, back of McGill University, Montreal, and in the Monteregian hills farther east. Far greater intruded masses are to be seen, however, in many places throughout New Brunswick and southern Quebec, and there are great granitic bathyliths at St. George and in the Little Megantic Mountains. Possibly also the crystalline rocks of the White Mountains of New Hampshire, and certain others in Vermont and Maine are of Devonian origin. With this folding, the rivers of Acadis were rejuvenated, marked erosion set in, and the resulting detrital materials (muds and sands) were carried into eastern Pennsylvania and New York and piled up in places to thicknesses of 13,000 feet. In Acadis and Gaspé the deposits of later Devonian time are of the continental or Old Red sandstone character and contain land plants and fresh-water fishes.

According to Dawson, throughout Nova Scotia, New Brunswick, and southern Quebec, the Carboniferous formations rest with marked unconformity upon the older rocks. This being so, the Acadian Disturbance is seen to be of very great import.

Disturbances in Other Continents. — In Lower Old Red times the northern half of the British Isles was the theater of igneous action on a large scale. To this time belong not only the very considerable accumulations of volcanic rocks in the midland belt of Scotland, in the Cheviots, and in County Tyrone, but as well a large part at least of the "newer granites," etc., of Scotland, along with other granites of the English lake district, and an important suite of minor intrusions (Harker 1909).

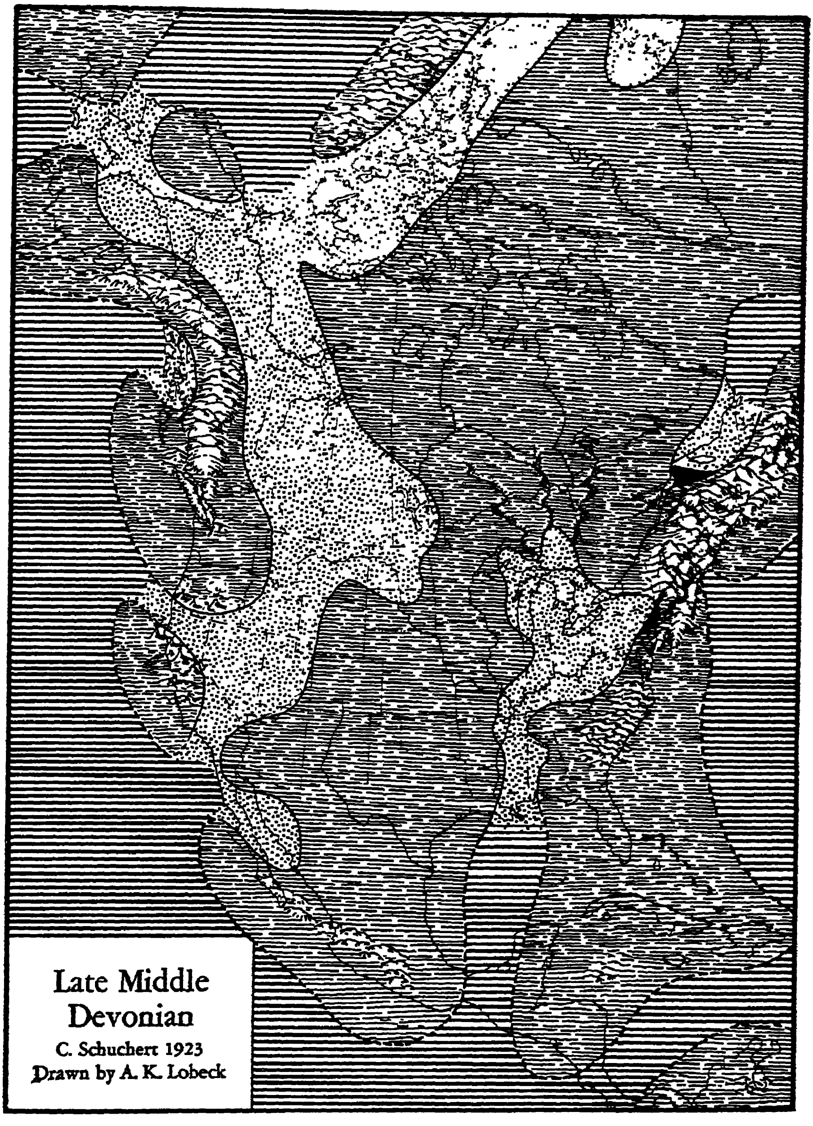

Plate 19. — Late Middle Devonian paleophysiography

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 18 (p. 313) for Devonian paleogeography.

The probable geography of late Middle Devonian time, when the Acadian mountains were rising (see p. 316), from which came the main mass of sediments in the great Appalachian delta (black area) described on pages 309–312, and that of Gaspé (p. 314). The other highland areas are hypothetic, and even though the drainage is unknown, some rivers have been sketched in. Note the volcanoes in California.

The lands were clothed with vegetation and in the lowlands there were forests, with trees up to 35 feet in height (pp. 327–330).

In the Christiania fiord of southern Norway there is also an area of about 4000 square miles that is intruded with igneous rocks of this time.

Throughout eastern Australia in late Devonian time there occurred the most marked mountain-making period of that continent, when the Kanimbla Mountains were elevated, trending north and south, and were intruded by granitic bathyliths (Suessmilch).

Fig. 108. — John Mason Clarke (1857–). Master of the American Devonian.

Marine Life of the Devonian

Provinces. — The Devonian marine life of the world is divisible into two great faunal realms: (1) the boreal, and (2) the austral. The latter is well developed in the Andean region of South America, the Falkland Islands, and South Africa. The boreal faunas are far more extensive and better understood, and those of North America may be arranged in three provinces. (1) In the Appalachian and Acadian areas the northern Atlantic waters dominated during the Lower Devonian and the life was in harmony with that of northern Europe (England and Rhineland); while throughout the balance of this period the faunal assemblages were those of the Central Interior sea. (2) The Central Interior sea to the west of the Cincinnati uplift, on the other hand, was dominated by life that was characteristic of this area and of Brazil, and it is sometimes referred to as the American faunal province. There was, however, a great difference between the two hemispheres, for in South America corals were practically absent. (3) The Cordilleric sea formed still another faunal province with most of its life derived from the northern Pacific or Euro-Asiatic province, and this biota was also wide-spread in the Arctic Ocean. This third province was wholly independent of the Central Interior sea until near the close of Middle Devonian time, when the two seas had communication across Iowa and Michigan. In the Upper Devonian the faunas again took on a cosmopolitan character, the Euro-Asiatic aspect

dominated most of the seas of this time, and its representatives are hence found in all three provinces.

Marine Invertebrates. — The seas after Lower Devonian time swarmed with corals, brachiopods, and shellfish, and in general the life was not very unlike that of the Silurian (see Pls., pp. 320–322). The corals were wide-spread, and are known from Louisville, Kentucky, north into Alaska. The Louisville reef is the one best known; it has a great abundance of species, with cup-corals over 24 inches long and more than 3 inches wide, and compound

Fig. 109. — Restorations of early Devonian marine life. Seaweeds, crinids (*Mariacrinus*), cephalopod (*Rhyticeras*) feeding on a trilobite (*Homalonotus*). Note also the highly ornate trilobite (*Terataspis*) beneath the crinid or feather-star. Original in New York State Museum. Photograph from John M. Clarke, Director.

colonies as much as 8 feet across (see Pl., p. 320, Figs. 4–8). There were also many bryozoans. Of the echinoderm type of animals, the blastids were now common and may have originated in America (see Pl., p. 320, Figs. 1–3). Starfishes were also at times abundant. Trilobites were still common, but greatly reduced in variety, there being about twenty genera and over one hundred species (see Fig., above, and Pl., p. 322, Figs. 7–12). The Devonian deposits are often full of brachiopods, of which there were no fewer than seven hundred different kinds in North America

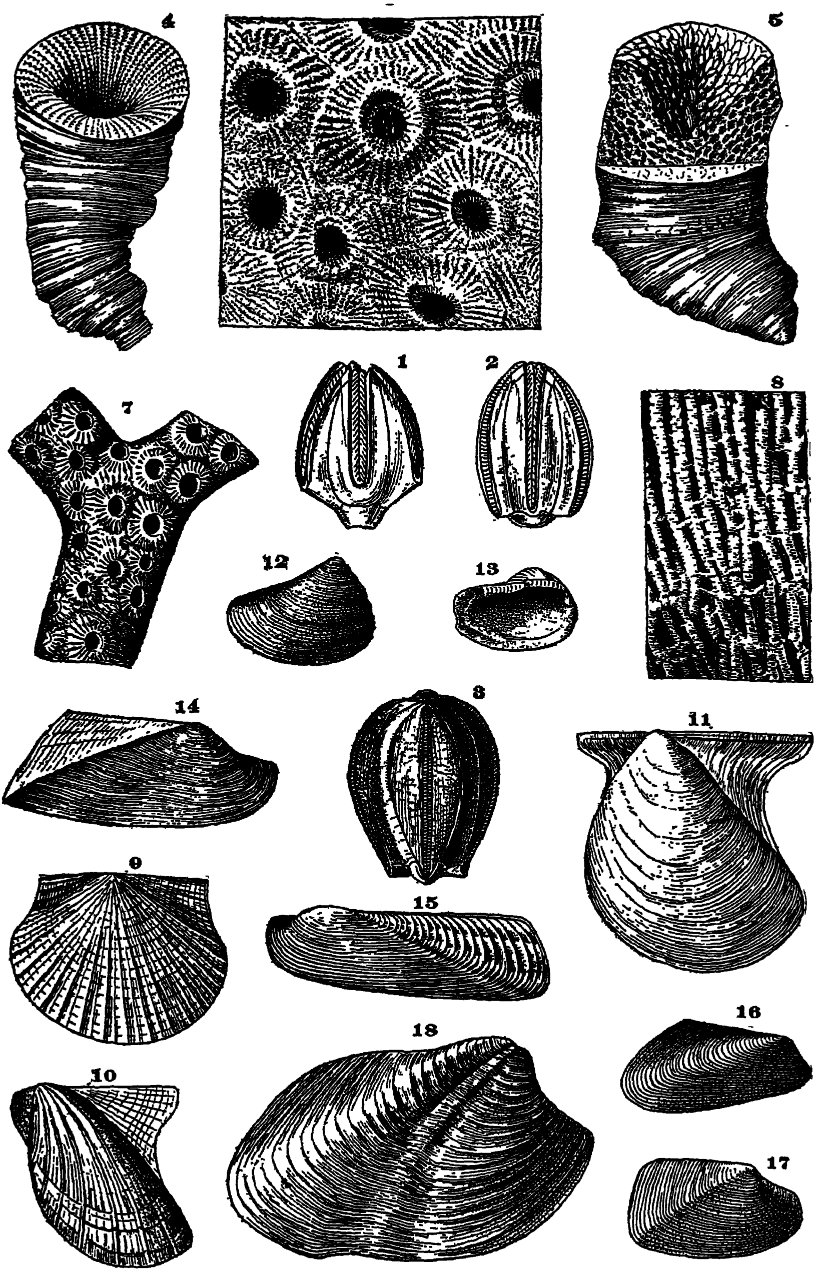

Plate 20. — Middle Devonian blastids (1–3), corals (4–8), and bivalves (9–18).

Fig. 1, *Pentremitidea filosa*, $\times 2$; 2, *Granatocrinus leda;* 3, *Elæacrinus verneuili;* 4, *Heliophyllum halli;* 5, *Cystiphyllum vesiculosum;* 6, *Phillipsastræa gigas;* 7, *Thamnoptychia limbata;* 8, *Syringopora perelegans;* 9, *Aviculopecten ornatus*, $\times \frac{2}{3}$; 10, *Pterinea flabellum*, $\times \frac{1}{2}$; 11, *Actinodesma erectum*, $\times \frac{2}{3}$; 12, 13, *Nucula randalli;* 14, *Goniophora carinata*, $\times \frac{2}{3}$; 15, *Orthonota undulata*, $\times \frac{2}{3}$; 16, *Modiomorpha concentrica*, $\times \frac{1}{3}$; 17, *Cypricardella bellistriata;* 18, *Grammysia bisulcata.*

From Paleontology of New York, and Geological Survey of Canada.

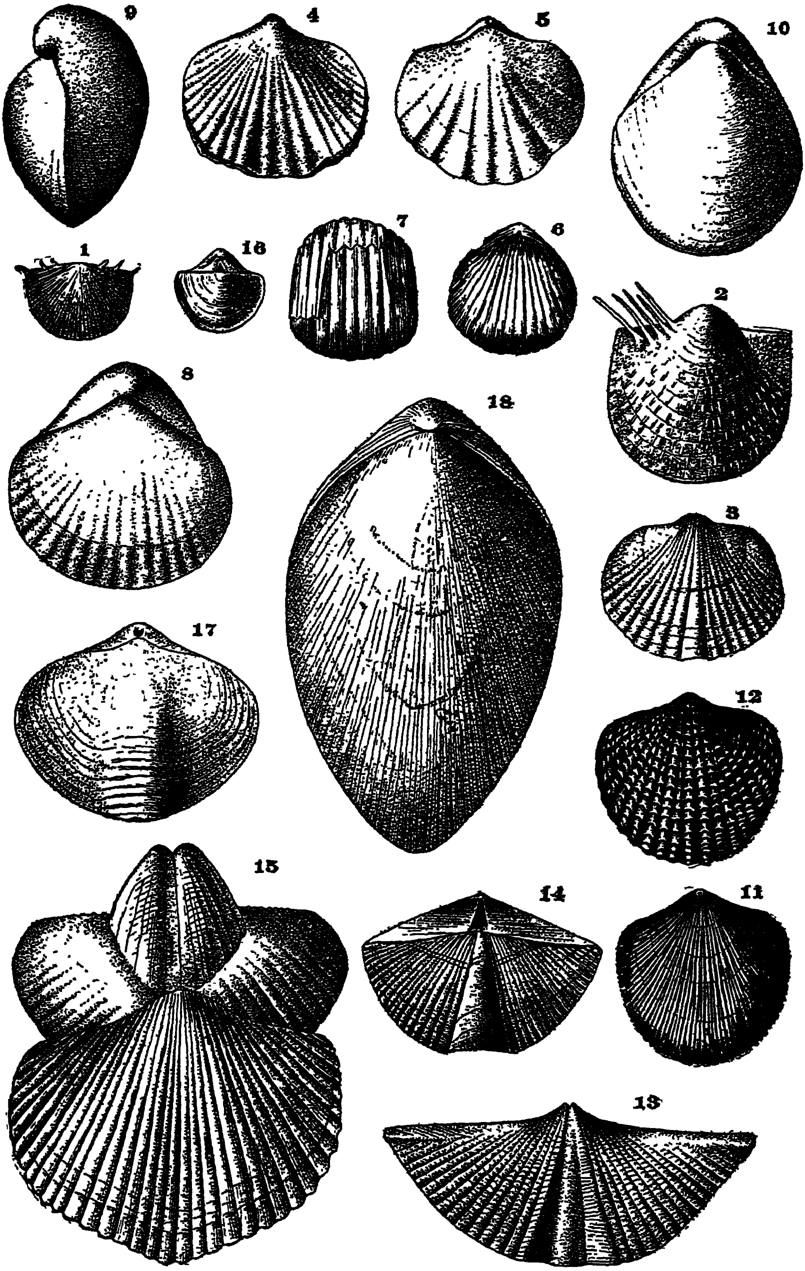

Plate 21. — Lower and Middle Devonian brachiopods.

. Fig. 1, *Chonetes setigerus;* 2, *Productella hirsuta* (Upper Devonian); 3, *Tropidoleptus carinatus;* 4, 5, *Eatonia medialis;* 6, 7, *Camarotœchia ventricosa;* 8, 9, *Gypidula coeymansensis;* 10, *Meristella lævis;* 11, *Atrypa reticularis;* 12, *A. spinosa;* 13, *Spirifer pennatus* (*mucronatus*); 14, *Spirifer medialis;* 15, interior cast and exterior of ventral valve of *Spirifer arenosus;* 16, *Ambocœlia umbonata,* × 2; 17, *Athyris spiriferoides;* 18, *Rensselæria ovoides.* From Paleontology of New York.

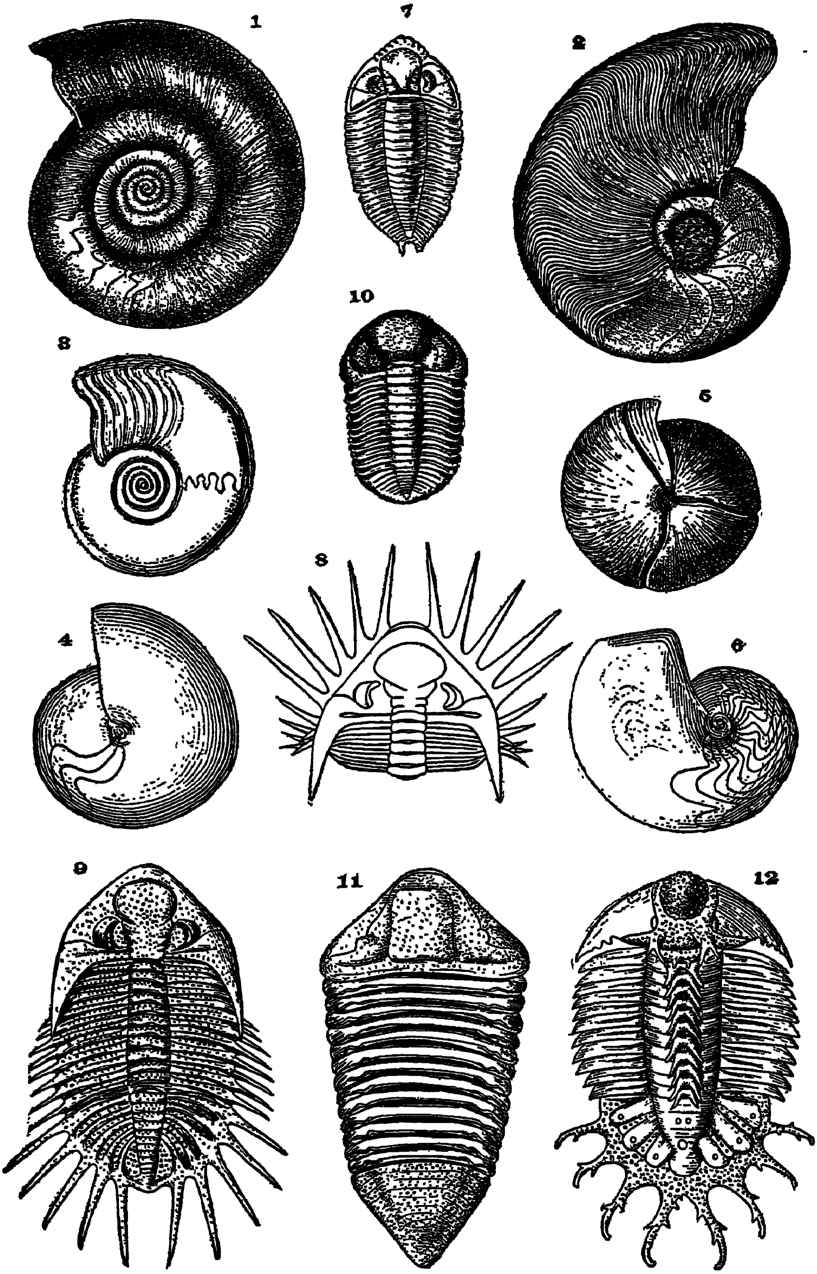

Plate 22. — Middle and Upper Devonian goniatites (1–6), and trilobites (7–12).

Fig. 1, *Oxyclymenia undulata* (Europe); 2, *Aphyllites vanuxemi*, $\times \frac{1}{3}$; 3, *Prolecanites lunulicosta* (Europe), $\times \frac{1}{2}$; 4, *Tornoceras simplex* (Europe); 5, *Brancoceras sulcatum* (Europe); 6, *Manticoceras oxy*, $\times \frac{1}{6}$; 7, *Odontocephalus selenurus*, $\times \frac{1}{4}$; 8, 9, rolled-up *Cryphæus punctatus*, and same extended (Europe); 10, *Phacops bufo;* 11, *Dipleura dekayi*, $\times \frac{1}{2}$; 12, *Terataspis grandis*, $\times \frac{1}{12}$.

Figs. 1–5, 9, 11 from Gürich's *Leitfossilien;* Fig. 8 after Richter; Figs. 6, 7, 10, 12 from Paleontology of New York.

(see Pl., p. 321), this being the time of their maximum development and differentiation. The most characteristic were the spire-bearing forms.

Comparing the American marine Devonian faunas with those of Europe, there is seen to be considerable dissimilarity, one especially marked difference being the development in the Old World of the *goniatites* (see Pl., p. 322, Figs. 1–6). There these animals appear in six genera at the very base of the Bohemian Devonian and are usually prolific throughout the later part of the period. They continued to be plentiful in the Mediterranean waters during subsequent Paleozoic time, but in America are usually rare fossils. Goniatites

Fig. 110. — Upper Devonian siliceous sponges and seaweeds. Restorations of specimens found about Olean, N. Y. Original in New York State Museum. Photograph from John M. Clarke, Director.

are cousins of the nautilids and gave rise in later Paleozoic time to the ammonids, the most characteristic marine animals of Mesozoic time. Goniatites are described in Chapter XXXVII.

Upper Devonian Sponge Colonies. — From southern central New York, J. M. Clarke has interestingly described at least five sponge colonies entombed in the Chemung sandstones. They are all of the glass type of sponges (hexactinellid Dictyospongidæ), and represent 90 species and 16 genera. More fossil glass sponges occur here, in fact, " than in all the rest of the world together." These sponges lived in waters thought to have been cold enough at times to have floating ice, and at depths of probably less than 300 feet, but in the present oceans the hundred kinds of glass sponges are inhabitants of waters ranging in depth from 570 to 17,000 feet.

Marine Fishes. — With the rise of the marine fishes one notes the decline of the trilobites and the nautilids, and it is probable that the fishes fed largely upon both of these types of animals. Beginning with Middle Devonian times, the teeth and spines of marine sharks are often met with. From Columbus, Ohio, northward to Lake Erie, there occurs locally a bed, sometimes 6 or more feet thick, made up of the broken bones of these and other fishes. They were in the main shell-feeders and ranged in length up to 6 feet. As they were in greatest development in the Mississippian, they are further described in the chapter on that period. In the Devonian the sharks made up about one third of all the kinds of fishes then existing.

The most striking fishes of the Devonian seas were the highly armored Arthrodira, and it is thought that about 40 per cent of all Devonian fishes were of this subclass. They are described in the previous chapter.

Devonian Fresh-Water Deposits and the Prophecy of Vertebrate Dominance

Fossiliferous Continental Formations. — The oldest fresh-water or continental deposits of Paleozoic time having an abundance of fossils are those of the Devonian, and especially of the Old Red sandstones of Scotland. From the Devonian period onward, the geologic record often bears testimony to the continental origin of certain deposits and their entombed life, and while such are preserved and accessible more and more as one goes upward in the geologic scale, still the record of the land-living and air-breathing plants and animals is far more imperfect than the record of marine life. This is due to the fact that the organisms of the land are rarely entombed in the sands and muds of the land waters, but are either eaten by their living contemporaries, or oxidized and blown away by the atmosphere. The life of the fresh waters is more apt to be preserved, along with such land-dwelling organisms as may be accidentally drowned or blown into them (leaves), or washed by the floods into the areas of standing waters where burial may take place. Even though burial occurs on land, however, the circulation of ground waters is far more marked in loose continental deposits than in the more completely cemented marine strata, and in this way nearly all the remains have been leached away.

Old Red of Scotland: Typical Continental Deposits. — The Old Red deposits of Britain are a tremendously thick series of coarse detritals

and volcanic effusives, seemingly accumulated in valleys between high mountains that were upheaved during the Caledonian Disturbance. Jukes-Browne states that there were probably five parallel ranges. The maximum thickness of these deposits may be as great as 37,000 feet, but in no single area is there more than 20,000 feet. Nowhere is there a transition, as has so often been stated, from the Silurian into the Old Red, for the contact is an unconformable one, and the break at the top with the Carboniferous is equally distinct. As long ago as 1856 Godwin-Austen regarded these deposits as of fresh-water origin, a conclusion now agreed to by nearly all geologists. They are probably wholly continental, and were accumulated in several independent and subsiding valleys, under a climate more or less arid. The record is a very long one and covers most of the Devonian, though sedimentation was interrupted for a considerable time during the Middle Devonian.

Old Red in America. — In America there are no fresh-water deposits of Devonian time that were accumulated in inland mountainous areas, like those of Scotland. They are, rather, delta deposits formed by large rivers flowing into the sea, apparently under a semiarid climate (see Fig., p. 311). Two of the non-marine animals are shown in Figs., pp. 326, 331. Clarke regards certain of the Upper Devonian deposits of New York (Oneonta and Catskill) and the sandstones of Gaspé in lower Quebec as of great coastal lagoons receiving terrigenous sediment rapidly and in vast quantity from a rapidly rising highland. In places there are thin, interbedded, marine zones that represent the overwash of the outside water in times of stress, bringing in the marine organisms as we find them — sea shells from the littoral. It is in these regions that are found the American Old Red fishes, most of which appear to have come from the rivers and not from the sea. The deposits of Scaumenac, Quebec, which are evenly bedded, gray to greenish, sandy shales, appear to be wholly of fresh-water delta origin, the only fossils being land plants and fresh-water fishes, in harmony with those of the Upper Devonian of Scotland. There occur eleven species of fishes (selachians three, ostracoderms three, dipnoans one, ganoids three). No marine fossil of any kind has ever been seen about Scaumenac.

Proof that the Old Red of Scotland is of Continental Origin. — These deposits are often very decidedly cross-bedded, and the materials are usually poorly assorted. The conglomerates are frequently of great thickness, with erratic bowlders as large as 8 feet in diameter. Ripple-marking is frequent, and the sun-cracking is deep, indicating that there was long exposure to dry

air, since the edges of the prisms are often curled. There are also present rain-drop impressions. All of these are characteristic of continental deposits. While the rocks are not red throughout the Old Red series, this is nevertheless the dominant color; it is usually due to the quartz grains being coated and held together by a crust of earthy ferric oxide very much as in the Triassic sandstones of the Connecticut valley, which are deposits of undoubted land origin under a semiarid climate. Further, Goodchild points out that some of the red sandstones of Scotland are often full of desert sand grains, and are highly false-bedded in places, like an old desert sand-dune.

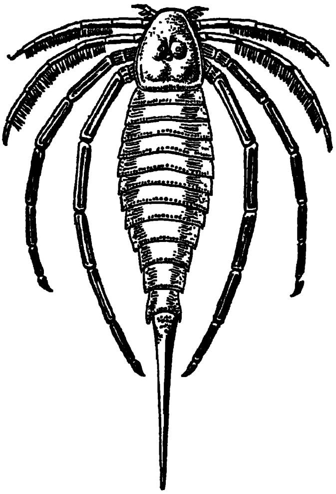

Fig. 111. — The large spike-tailed eurypterid, *Stylonurus excelsior*, × $\frac{1}{24}$. After Clarke and Ruedemann.

In the Old Red there are no thick, evenly bedded limestones, and the amount of carbonate of lime present at certain horizons is not greater than that found in undoubted continental deposits. The Old Red abounds in land plants and most of the fishes are of unmistakable fresh-water types, ranging in length up to 30 inches. Of true marine animals there are none, though the small sharks and the small to gigantic eurypterids may have migrated from such waters. With none of these, however, are associated marine shells, and on the other hand it is well known that a few kinds of sharks are living to-day in fresh waters. If sharks adapt themselves to fresh waters now, why may they not have done so in the past? Therefore, the only evidence against the view that the Old Red is of continental origin is that of the eurypterids.

Eurypterids (Pl., p. 276) are locally abundant in the lowest beds, one even attaining a length of 6 feet. These are known to the Scotch quarrymen as "seraphims." Previous to the Old Red, all eurypterids occur in unmistakably marine or at least estuarine associations, but toward the close of the Silurian, both in Europe and America, they are nearly always restricted to brackish-water assemblages. After Silurian time none of these animals are found in normal marine associations, and the last occur in the Pennsylvanian, where they again appear either in brackish-water faunas or in association with land plants and with a complete absence of marine animals. It is therefore held, and justifiably so, that the later eurypterids traveled far up the estuaries and even into the fresh-water rivers either in search of food or more probably to spawn.

Mixed Marine and Fresh-water Faunas. — Wherever the Old Red fishes are found associated with marine faunas, it is seen that such mixtures have taken place near the shore lines of the Devonian epeiric and shelf seas. Therefore these occurrences may be cases of moribund fresh-water animals floated to the sea by the rivers, or they may be of species that have interchangeable marine and fresh-water habitats, as have many modern fishes, such as the salmon. Kayser, and more especially Walther, hold that the Old Red areas were lagoons of the sea in which the character of the water recurrently changed; for long intervals the sea was present in the lagoons, followed by equally long periods when it was out of them, or the rivers dried out before attaining the sea and then over the areas of the deltas were deposited irregularly variable sheets of desert deposits derived from the highlands. On the other hand, Barrell holds that the Old Red deposits are wholly of river origin, with local lakes and swamps: flood-plain deposits under seasonal rainfall of a semiarid climate.

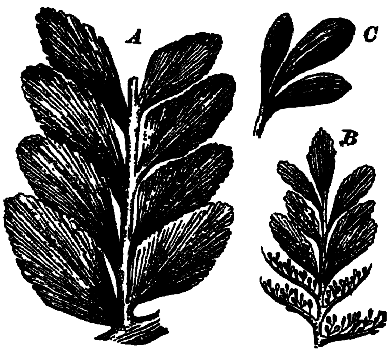

Fig. 112. — Characteristic fern-like plant of Devonian time (*Archæopteris hibernica*). *A*, sterile branch, somewhat enlarged to show venation of leaves. *B*, fertile branch, about natural size. *C*, seed cases, much enlarged. After Schimper and Schenk.

We are reminded by the Old Red of the Teri region of southern India, where the wide coastal plain is covered by wandering dunes of carmine red sands nearly two hundred feet high, between which are beautiful dark blue lakes whose shores are decorated with palms. Here are forming thick red sandstones with typical dune-bedding, beside thin-banded red clays at the bottoms of the lakes. Not far away are being deposited marine limestones and sandstones decidedly rich in beautiful pearl shells and snails, which gradually pass into coral reefs with their teeming life. Just as these sands of Teri are coated with a thin layer of iron oxide, so were those of the Old Red, and we cannot escape the conviction that both were caused by identical semiarid climatic conditions. (Walther.)

Plants and the Climate. — In the Devonian there is much evidence of land plants, but it is not until the Middle Devonian that we can speak of floras, for in the Lower Devonian these fossils are still very scarce. In the Upper Devonian there was a considerably diversified flora, forming the oldest or first forest, in which florished fern-like plants, fern-like seed trees (*Eospermatopteris*), rushes, tall ground pines (lycopods), and primitive evergreens with woody trunks nearly

2 feet in diameter. Drifted logs of these trees are often found in the marine deposits of Upper Devonian time. At Gilboa in the Schoharie valley, New York, have been found about thirty great stumps and spreading roots of tall trees still standing in their native soil. They attained a height of 30 to 40 feet and are thought to have been seed-ferns. As the dominant plants of this cosmopolitan flora were fern-like forms, it has been called, after one of

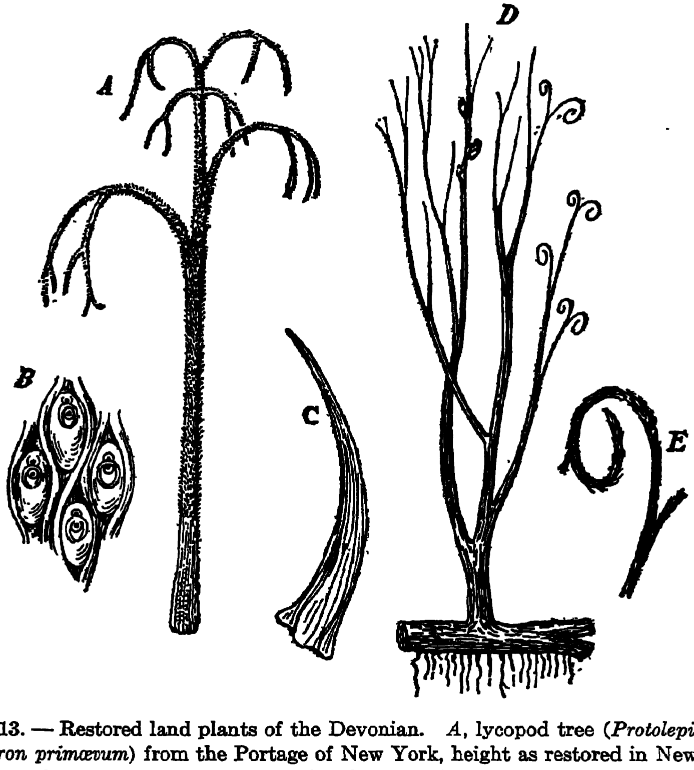

Fig. 113. — Restored land plants of the Devonian. *A*, lycopod tree (*Protolepidodendron primævum*) from the Portage of New York, height as restored in New York State Museum about 20 feet; *B*, leaf bases, and *C*, needle-leaf of same tree; *D*, a very primitive plant (*Psilophyton princeps*) attaining a height of several feet, as restored by Dawson with fructifications. *E*, terminal branch of same, enlarged.

them, the Archæopteris flora, and the time, the *Age of Archæopteris* (see Fig., p. 327). As the flora in its broader aspect was not very unlike that of Pennsylvanian time, the detailed description of it is deferred to Chapter XXVIII. The Devonian forests, however, were devoid of all insects. One of the most remarkable facts in connection with this flora was its wide distribution and uniform character throughout eastern North America and into the Arctic region, Spitzbergen, and northwestern Europe, indicating equable

climates and the complete union of North America and Europe across Greenland, Spitzbergen, Norway, and Great Britain. None of the trees show annual rings of growth attesting to seasonal changes due to a varying climate or to prolonged drought and it is therefore held that the general climate of this time was uniformly warm though semiarid, the known forests being localized in wet places along the valleys and in the swamp areas. That the climate was warm is further shown in the wide distribution of the reef corals of the seas, which extended even into Arctic regions, but that the air was more or less semiarid is proved by the prevalence of the oxidized and red continental deposits of Eris. Locally, however, there must have been winters, for J. M. Clarke has demonstrated the presence of shore ice during Upper Devonian times in central New York and at Scaumenac, Quebec. Kirk also describes Upper Devonian ice-facetted rocks in southeastern Alaska (1918). The "striated" pebbles reported in the deformed Table Mountain series of South Africa, however, turn out to be squeezed and slickensided stones (Daly 1923).

Thin coal beds of very local distribution are occasionally observed in the Old Red continental deposits, but these, as a rule, are of no commercial value; to the scientist, however, they indicate that swampy areas abounding in plants occurred where the coals are found. On Bear Island, to the north of Norway, are found beds of good bituminous coal sometimes 3.5 feet in depth.

Rise of Land Plants. — In Chapter II something was said about the origin of land plants out of the marine seaweeds. We will now follow the subject further. A. H. Church (1919) holds that the chief structural characters of the land flora were first outlined in the sea. In their very difficult migration from the sea to the dry lands, the algæ needed to provide themselves with absorptive instead of merely anchoring roots, and with a water-conducting system. In fact, the oldest well-known land plants (*Rhynia* and *Hornea*) are nothing more than branching duct-bearing stems, not over 8 inches tall, covered with scattered breathing pores (stomata), and specialized tips or sporangial areas for the development of spores. Such were recently discovered in the Old Red of Scotland, with all the microstructure preserved. *Rhynia* and *Hornea* are without roots, leaves, or aërial appendages, and therefore are but little more advanced structurally than the seaweeds of the present. *Psilophyton* of Dawson is very closely related, and all are said to be of the Psilophyton flora. These plants were fitted, however, for terrestrial life. They may be regarded as Thallophytes, intermediate toward the fern-like plants (Pteridophyta). (See Figs., pp. 328, 330.)

The land plants of the Lower Devonian and of earlier periods are much more primitive than those of the first land floras of the Middle and Upper Devonian, and in their structures show that the fern-like plants (Pteridophyta), moss-like plants (Bryophyta), and seaweeds are of one line of descent. It appears that before the Middle Devonian there were no ferns at all. In the later De-

vonian, along with the fern-like plants, there were also ancient conifer-like trees, and Scott hints that the seed-bearing plants may not have arisen in the ferns as is generally believed, but rather that both stocks go back to more ancient times, and to plants like *Rhynia* and *Hornea*.

Devonian Fresh-water Fishes. — The fresh waters of Devonian time must have abounded in life, an inference justified by the fact that over one hundred species of fishes alone, in more than forty genera, are known in the continental deposits of this time. In the Orkneys at Stromness the Old Red sandstones are at certain horizons replete with fishes. In fact, they are so common that Hugh Miller calls this area "a land of fish". As fishes are fully discussed and illustrated in the previous chapter, we need here only present a general summary of the Devonian kinds (see Pls., pp. 291 and 295). These were primitive in that they did not have well developed internal skeletons, and in that the latter were more cartilaginous than bony. The median fins were often continuous, or a series of fins, extending along the dorsal and ventral surfaces and meeting around the end of the tail. The vertebral column often extended to the end of the tail, with the continuous fin all around it, the diphycercal type of tail. The heterocercal tail was the other common type.

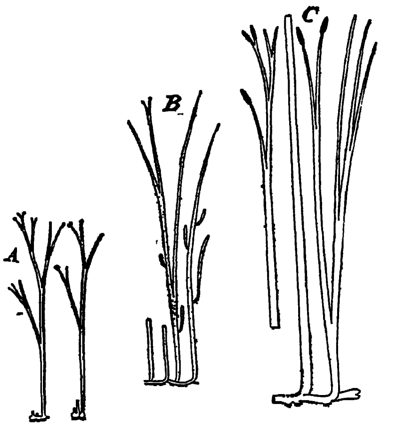

Fig. 114. — Restorations of the most primitive of known land plants, having the characters of seaweeds, mosses, and ferns. From the Lower Devonian of Scotland. *A*, a form of *Hornea*, *B* and *C*, of *Rhynia*, neither more than 8 inches tall, and both related to *Psilophyton* (Fig., p. 328). After Kidston and Lang.

The oldest forms were small fresh-water spinous sharks known as acanthodians, which vanished from the rivers before the close of the Devonian. In the Lower Devonian appeared various kinds of ganoids, fishes related to the living sturgeons and gar-pike; in present waters they are not at all common, but in the Devonian they made up almost one quarter of all the fishes of this period. There were also many lung-fishes or dipnoans.

Among the Devonian fresh-water fishes, and probably arousing more speculation than any others, are the "winged" fishes known

as Ostracodermi (means shell- or bony-skinned), described at length in the previous chapter.

Food of Devonian Fresh-water Fishes. — In the fresh-water deposits of Devonian time there is not as yet known a single definitely determined water-living plant, nor invertebrates of any kind other than bivalves (see Fig., opposite) and myriapods. The ultimate basis of fish food, however, must have been water plants and algæ. There was probably also an abundance of earthworms present, though their bodies were too soft for preservation as fossils. The sluggish bottom-living Devonian fishes were, then, dependent upon water plants, and upon these fishes subsisted the more active carnivorous forms. That food was still scarce in the streams and lakes of Devonian time is attested by the average small size of these ancient fishes, few of which exceeded 9 inches in length. In the marine waters where food was plentiful, the average length of fishes was far greater, and one at least of the Arthrodira attained 20 feet. It was probably because of the abundance of food in the seas and oceans that we see so many different stocks of land fishes returning and adapting themselves to these more favorable habitats.

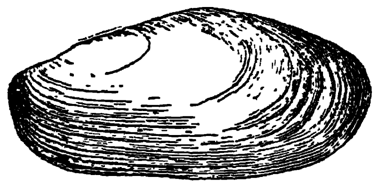

Fig. 115.— Probable fresh-water Devonian bivalve (*Amnigenia catskillensis*), from New York. × ½. After Hall.

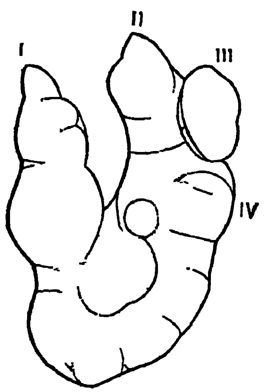

Fig. 116.—The oldest known amphibian footprint (*Thinopus antiquus*), from the Upper Devonian of Pennsylvania, one half natural size. I and II are fully formed toes, III a budding toe, IV probably a rudimentary toe. Original at Yale University. After Lull.

Amphibia. — Of vertebrates higher than the fishes, the only evidence rests upon one foot imprint (*Thinopus antiquus*) nearly 4 inches long, which was found near the top of the Upper Devonian of western Pennsylvania (Fig., left, above). This indicates the presence of a salamander-like animal (stegocephalian) with a probable length of nearly 3 feet. The track is from a marine sandstone of the littoral or beach area over which the animal walked, probably in search of dead marine life. This stratum is associated with others that are ripple-marked and sun-cracked, and bear rain imprints.

Collateral Reading

J. Barrell, The Upper Devonian Delta of the Appalachian Geosyncline. American Journal of Science, 4th series, Vol. 36, 1913, pp. 429–472, Vol. 37, 1914, pp. 87–109, 225–253.

W. B. Clark, Maryland Geological Survey, Devonian volumes, 1913.

John M. Clarke, Strand and Undertow Markings of Upper Devonian Time as Indications of the Prevailing Climate. New York State Museum, Bull. 196, 1917, pp. 199–238.

John M. Clarke, Early Devonic of New York and Eastern North America. New York State Museum, Memoir 9, 1908-1909.

John M. Clarke, Naples Fauna in Western New York. New York State Museum, Memoir 6, 1903.

John M. Clarke, (Restorations of Devonian Life), New York State Museum, Report of the Director for 1917, 1919, opposite p. 24.

Hugh Miller, Old Red Sandstone, 1851.

CHAPTER XXV

THE MISSISSIPPIAN PERIOD AND THE CLIMAX OF CRINIDS AND ANCIENT SHARKS

History of the Term Carboniferous. — The Upper Paleozoic rocks were once regarded as comprising but a single period of time, and because coal (carbon) is common in them, they were called the *Carboniferous System*. In western Europe, where Geology had its inception, the coal-bearing strata are of wide occurrence, and as long ago as 1808 Omalius d'Halloy wrote "bituminous terraine" for the coal deposits of Belgium. In England the miners have long used the term "Coal Measures," and it was John Phillips of that country who in 1839 proposed the name Carboniferous System. The term was then applied to all the strata above the Old Red sandstone or Devonian and beneath the New Red sandstone or Triassic. At present the Europeans recognize two systems, the Carboniferous and Permian, while in America three are now accepted.

The present American classification of the Carboniferous strata may be contrasted with that of Europe as follows:

Europe	America
Permian period	Permian period
	Break not general
Upper Carboniferous or Coal Measures	Pennsylvanian period or Coal Measures
	Break general
Lower Carboniferous (Culm) or Dinantian Upper or Viséan Lower or Tournaician	Mississippian period or Subcarboniferous Upper or Tennesseian Lower or Waverlian

The Productus Seas. — The seas of the three Carboniferous periods the world over were characterized by an abundance and great variety of brachiopods of the genus *Productus* (see Pl., p. 365, Figs. 5–11), and have hence been called the *Productus seas*. These shells are always common, and as they are of large size, they are the most conspicuous and easily secured fossils of the Carboniferous marine

formations. Further, as the genus died out during Permian time, they are the best guide fossils to the Carboniferous strata. It is true that this stock arose in the Middle Devonian, but even though the forms of the ancestral genus *Productella* were not rare in the Upper Devonian, they were then neither large nor common enough to dominate the marine faunas as they did in the Carboniferous throughout the world.

Mississippian Period

Significant Things about the Mississippian Period. — Eastern North America at this time was occupied by the old land, greater Appalachis, and as it had been re-elevated at the close of the Devonian, it was natural that the shallow seaways to the west of it as far as the Cincinnati arch should be depositing much mud and sandstone and but little limestone. In the Mississippi valley the small seaways had clearer water, and here the dominant rocks are limestones and oölites. Along the Pacific coast was the old land Cascadis and to the east of it lay a wide shallow sea. At times this, the Madison limestone-making sea, connected with the marine waters of the Mississippi valley.

Toward the close of the period, mountains arose in the southern Appalachian area, in Arkansas and Oklahoma, in Nova Scotia and New Brunswick, and in central Europe.

The marine life of the Mississippian is noted for its many kinds of *Pentremites*, the first abundance of echinids, the peculiar screw-like bryozoans known as *Archimedes*, the many productids, and especially for the vast quantity of crinids and crinidal limestones and the many shell-feeding sharks. Of the land floras little is known in North America, and of the amphibians only some foot impressions. There are as yet no commercially valuable coals known in America, other than at Cape Lisburne, Alaska.

The geologic record of Mississippian time in North America is markedly different from that of the Pennsylvanian, for the former is one chiefly of the sea, while in the latter in the eastern half of the continent there is an alternation of the sediments of marine floodings with accumulations of coal beds in vast more or less fresh-water swamps. In other words, the Mississippian is a recurrence of Devonian conditions, while the Pennsylvanian formations alternate between those of the sea and land.

The Term Mississippian. — At first this system of rocks was known in North America as the Lower Carboniferous or Subcarboniferous (Owen 1852). A part of these strata in Ohio was also known as

the *Waverly sandstone series* (Mather 1838), but not until 1869 was a geographic name proposed to embrace all of the Lower Carboniferous strata. This was the *Mississippi Group* of Alexander Winchell, who applied the term to the Lower "Carboniferous Limestones of the United States which are so largely developed in the valley of the Mississippi River." In 1891, Professor H. S. Williams revived this term as the *Mississippian series*, defining it as "that series of rocks, prevailingly calcareous, which occupies the interval between the Devonian system and the Coal Measures." This name is now in general use as a period term.

TABLE OF MISSISSIPPIAN FORMATIONS

Complete break with Pennsylvanian

Late Mississippian or Tennesseian	Parkwood of Alabama (2000′)				
	Chesterian	A very variable series of limestones and sandstones indicative of rising lands		Mauch Chunk, Greenbrier, Maxville	
	Marked break in northern half of Mississippi valley				
	Iowan	Ste. Genevieve			
		Meramecian	St. Louis, Salem, Warsaw	Chiefly limestones and oölites	
	Marked changes in seaways				
Early Mississippian or Waverlian	Osagian	Boone	Keokuk-Fort Payne-Logan		Madison of Rocky Mts.
			Burlington-Cuyahoga, Fern Glen	Pocono	
	Wider spread of seas				
	Kinderhookian	Chouteau, Rockford, Glen Park, Louisiana			
	Chattanoogan	Sunbury, Berea, Bedford, Cleveland			

Complete break with Devonian

Early Mississippian Time (Waverlian)

Waverlian Seas. — The Devonian period closed with marked retreat of the seas in North America and it appears that all parts of the continent were emergent. How long this complete emergence lasted is not known. The submergence of Waverlian time began first in the Gulf States and along the western side of the Cincinnati uplift. At this early stage of the inundation the seas were small in extent but in Middle Kinderhookian time the waterways were greatly

expanded. The most striking change of this time, however, was the reappearance of the *Cordilleric sea,* depositing far and wide throughout the Rocky Mountains a great mass of limestones, known as the Madison limestone, that in places attains to a thickness of 1600 feet. It is exceedingly massive and where uplifted the streams have cut in many places deep and picturesque canyons through it. This Cordilleric sea is known in Alberta (Lower Banff shale and limestone with a thickness of 2300 feet), on the Liard River in the Mackenzie region, and probably extended into the Arctic Ocean. That it connected at times with the Central Interior sea either across Colorado or New Mexico into Kansas and Oklahoma, is proved by identical species in both; in fact, more than one third of the Cordilleran forms also occur in the Central Interior sea. The Cordilleric sea, then, remained throughout Waverlian time and seemingly vanished completely at the close of this epoch, to reappear greatly altered in its geography in the later Tennesseian. During the maximum submergence of Waverlian time about 26 per cent of North America was under the sea.

The *northern Appalachic basin* existed throughout Waverlian time east and north of the Cincinnati uplift in the states of Ohio, Michigan, and Pennsylvania, and it is from this area (Waverly, Ohio) that the epoch name is derived. The life of this basin also had its own impress, but as there were many species common to it and the Central Interior sea it is plain that they were connected.

It was a shallow basin with coarse deposits throughout: sandstones and shales, with some conglomerates and but little calcareous material. Eastward, these deposits pass into the Pocono series of fresh-water and brackish-water origin (400–1400 feet), of Pennsylvania, Maryland, and Virginia. Here also occur the oldest American coal beds, thin accumulations of little commercial value but prophetic of the thicker beds occurring in later formations. However, coal was forming early in Waverlian time in other and widely separated places, as in arctic Alaska (Capes Lisburne and Thompson), southern Siberia, and Scotland; and later thin coal beds were accumulating in western Europe in some of the Culm deposits. At Cape Lisburne the coals are non-coking and semi-bituminous, in beds up to 4 feet thick of clean coal, which is now mined.

In the *Central Interior sea* the invasion began with black mud deposits almost devoid of fossils (Chattanoogan) and for a long time the sediments were of this character, with local sand accumulations. During Kinderhookian time the waters west of the Cincinnati uplift clarified and then for a long time remained clear, depositing over great areas the later Kinderhookian and Burlington crinidal limestones. The entire thickness of Waverlian deposits at Burlington,

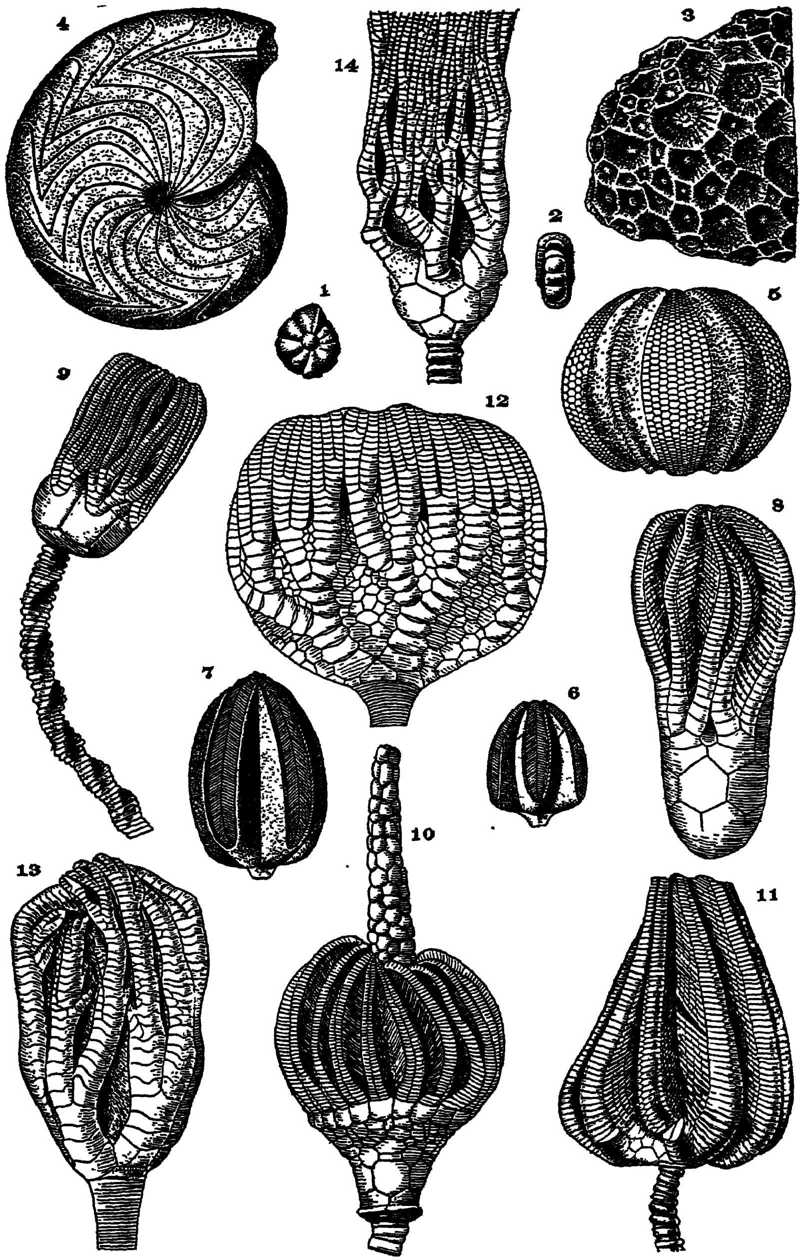

Plate 23. — Mississippian Protozoa (1, 2), reef-coral (3), goniatid (4), sea-urchin (5), blastids (6, 7), and crinids (8–14, 9–11 camerate).

Figs. 1, 2, *Endothyra baileyi*, $\times 9$; 3, *Axinura canadensis*, $\times \frac{1}{2}$; 4, *Brancoceras ixion*, $\times \frac{1}{2}$; 5, *Melonechinus multiporus*, $\times \frac{1}{3}$; 6, *Pentremites conoideus*; 7, *P. elongatus*; 8, *Agassizocrinus dactyliformis*, $\times \frac{2}{3}$; 9, *Platycrinus symmetricus*; 10, *Batocrinus pyriformis*, $\times \frac{2}{3}$; 11, *Agaricocrinus bullatus*; 12, *Forbesiocrinus wortheni*, $\times \frac{2}{3}$; 13, *Onychocrinus ramulosus*, $\times \frac{2}{3}$; 14, *Cyathocrinus multibrachiatus*. In the main after

Iowa, is about 300 feet, but the series thickens considerably to the south.

In the *Acadian area* of New Brunswick and Nova Scotia there was another basin of deposition, but wholly of continental strata. Here were laid down the dark-colored Horton and Albert formations of arkoses, conglomerates, feldspathic and muddy sandstones, and micaceous siliceous shales, attaining a thickness varying between 2800 and 3400 feet. In the Horton, W. A. Bell has counted no fewer than fifty-six dirt beds which represent preserved swamp soils of this time. They are replete with the fossilized roots of Waverlian plants, and in some of them are still seen the erect stumps of small trees (*Lepidodendron corrugatum*). On a surface 150 by 15 feet were counted ninety-six vertical trunks embedded in a

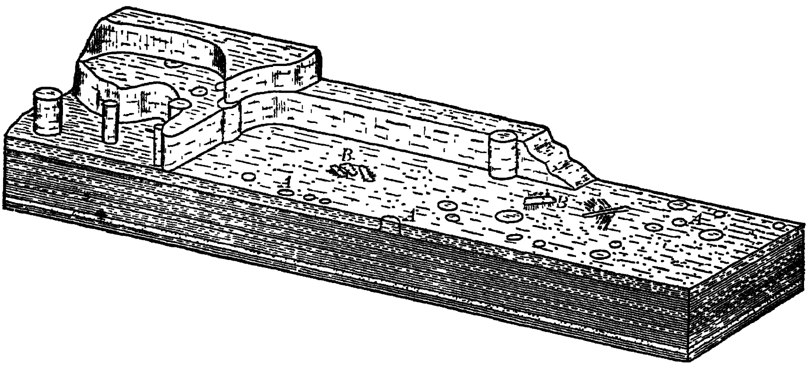

Fig. 117. — Ground plan to scale ($\frac{1}{87}$) to show twenty-seven vertical trees (*Lepidodendron*) in Mississippian strata at Horton Bluff, Nova Scotia. *A*, trunks; *B*, roots. Area sketched 22 × 6 feet. Drawn by W. A. Bell.

dark greenish sandy mudstone. A part of this layer is illustrated in the figure above. Some of the beds of the Albert series abound in a few species of fresh-water ganoid fishes.

Farther north in southern Quebec there is another thick series, but here of red beds, long known as the *Bonaventure formation*, a series of sometimes very coarse conglomerates, sandstones, and sandy shales. They are of fresh-water origin. The conglomerates are of the older formations and the pebbles are in the main of the fossiliferous Devonian, Silurian, and Champlainian. The brick-red color of the Bonaventure strata is not in keeping with the color of Waverlian deposits, and it may be that they are actually of late Tennesseian time.

Diastrophism at the Close of Waverlian Time. — The Waverlian submergence was at its height late in the Burlington and the seas began to retreat in Keokuk time, persisting longest in the Cordilleran region. The Central Interior sea again became muddy in the north,

where shales and sandy shales dominate, and even the limestones farther south are less pure than those of earlier time. Toward the close of the Keokuk the withdrawal of the seas was widespread though not complete in the Central Interior region. Local mountain making took place in Nova Scotia and New Brunswick toward the close of the Waverlian, since the Tennesseian deposits (Cheverie and Windsor series) are here not strictly in conformity with the continental deposits of the Waverlian (Horton). The greatest geographic change, however, took place in the western part of North America, since it appears that the Cordilleric geosyncline became dry land and remained so until late in the Tennesseian, when the seas returned but changed greatly in geographic distribution. It is this emergence that leads to the separation of the Mississippian into two divisions as shown in the table on page 335.

Late Mississippian Time (Tennesseian)

Lands and Seas. — The seas of Tennesseian time early in the Meramecian (see table, p. 335) began a renewed spread in the *Central Interior area* and attained their maximum spread early in the Chesterian. At no time, however, were these epeiric seas so extensive as those of the Waverlian. It appears that never was more than 12 per cent of the medial portion of North America submerged, while the average for the epoch may have been about 8 per cent. Nowhere are there more than 1100 to 1800 feet of sediments, most of which in the center of the area are limestones and oölites. On the flanks, and especially along southern Appalachis, there are sandy or calcareous marine shales that attain a thickness of several thousand feet, but the deposits in the northeastern part of this trough are, in the main, of continental origin, being soft, red, sandy shales devoid of marine fossils (Mauch Chunk, at Pottsville, Pennsylvania, 3000 feet thick, thinning to 600 feet in western Pennsylvania and 40 feet in West Virginia).

The area of the Tennesseian limestones of western Kentucky, which includes the celebrated Mammoth Cave, has been called "the land of ten thousand sink holes". More than 9000 of these solution holes have already been mapped, and it is estimated that when the United States Geological Survey completes its work, something like 60,000 of them will have been located. They are of all sizes, the largest one covering 3100 acres. (W. R. Jillson.)

In the *Acadian area* there was another sea of this time, consisting of narrow connected troughs between mountain ranges made during the Acadian Disturbance. These seaways deposited conglomerates,

sands, much mud, thin zones of dolomites, and great quantities of gypsum. At the top the series commonly has extensive sheets of igneous rocks. These Acadian deposits are known as the *Cheverie* and *Windsor series* and at times are rich in fossils. The fauna is a distinct one and has no close relationship to those of other seas, though Bell has shown it to be somewhat related to English faunas. The thickness of the rocks is estimated at about 2000 feet, and the formations occur in New Brunswick, Nova Scotia, and southwestern Newfoundland.

In the *Cordilleran area* a great geographic change appears to have taken place at the close of the Waverlian, since the eastern shore of the heretofore very wide Cordilleric geosyncline was apparently shifted to western Colorado, Wyoming, Montana, and Alberta, thus narrowing considerably the area of this trough. Seemingly, this warping movement took place at the close of the Madison deposition and before the introduction here of the late Tennesseian formations that have Pacific faunas. South of Colorado the Cordilleric trough still remained very wide, the narrowing not taking place until the close of the Pennsylvanian.

The marine life of the western or Pacific waters during the Tennesseian was markedly different from that of the Central Interior sea. These western life assemblages contrast sharply with those of the Mississippi valley in the almost complete absence of *Pentremites*, crinids, and *Archimedes* so common in the east. Goniatites, *Leiorhynchus*, *Posidonia* (*Caneyella*) and other elements of the associated black shale deposits (facies) spread into Missouri and Arkansas. It is in these western seas that we meet also with the *Productus giganteus* fauna characterizing the Viséan of Europe, but in the Cordilleric seas it is associated with Asiatic forms.

Life of Mississippian Time

Marine Life. — In Middle Waverlian times the life was most diversified, and the sea was filled with an abundance of crinids in great variety, a richness of development never again attained by this class of radiate animals (Pl., p. 337, Figs. 8–14). They were at first delicate forms, becoming larger, thicker plated, coarser, and more ornate with the progress of time. About the city of Burlington alone nearly four hundred species have been found and through the quarrying of the limestones these fine fossils became readily accessible, thus stimulating several collectors living in the city to turn to natural history and geology as a vocation. In the Tennesseian the crinids were far less diversified. Other kinds of fossils were also abundant in

the Waverlian seas, as, for instance, brachiopods (*Productus*, *Spirifer*), bryozoans, and cup corals, but none attained the profusion of the crinids. That reef-building corals were not present in this warm and clear sea is strange, since reefs were made at this time in Europe. Among cephalopods, the nautilids were no longer so prevalent as they were in earlier times. Their descendants, the goniatites, (Pl., p. 337, Fig. 4) were now rising into ascendency, and were more common than in the Devonian, but this statement applies rather to the European seas than to the Central Interior sea. Trilobites were almost gone. The carnivorous or aggressive life of the Waverlian sea was therefore dominated by the shell-feeding sharks. It is interesting to note here that the life of the Waverlian sea was much like that of western Europe, seen to best advantage in the equivalent strata of Belgium (Tournaician), indicating that these waters were in connection with each other.

The marine life of the Tennesseian of the Central Interior sea differs in many ways from that of the Waverlian, but as it is largely a direct outgrowth of the latter it naturally cannot vary greatly. One of the noticeable features of this life is a dwarf fauna of more than seventy species which reappears at least four times but is always connected with the same physical environment, shallow-water oölite deposits. This life assemblage of dwarf forms is known as the Salem fauna because it is best developed in the Salem formation of Indiana. In the Tennesseian, two groups of echinoderms were well developed. These were the blastids (*Pentremites*, Pl., p. 337, Figs. 6, 7) described elsewhere (p. 349), which are the guide fossils to the marine deposits of this time, and in places are so common that geologists have called the beds the Pentremital limestone; and, associated with them, though far less common, the equally characteristic sea-urchins known as *Melonechinus* (the melon-like urchin, see Pl., p. 337, Fig. 5; and Fig. *C*, p. 347). Bryozoa with a thick, screw-like axis (*Archimedes*) were also characteristic of this epoch and certain horizons filled with them have been called the Archimedes limestone. There were small cup corals, and one type of compound coral (*Axinura*, see Pl., p. 337, Fig. 3).

Shell-feeding Sharks of Mississippian Seas. — Large sharks of the shell-feeding type were becoming more and more plentiful during Waverlian time, for their flat, crushing teeth and large fin spines are often abundant, and especially so toward the close of the epoch (Keokuk). See Fig., p. 342.

Very small "spinose sharks" (acanthodians, see Pl., p. 295, Fig. 1), rarely more than 6 inches long, appear in the late Silurian, and the first of the shell-

feeding sharks (Pl., p. 295, Fig. 3) are known in the following period. In the American Devonian there are 39 species, in the Mississippian 288, in the Pennsylvanian 55, and in the Permian 10. Therefore there was apparently a very rapid evolution of the sharks in the Waverlian, when they were the dominant marine fishes, with a quick decline during the Tennesseian, the history being the same in Europe. These sharks were all of primitive types, that is, the acanthodians were least in number, and by far the commonest were those with pavement-like teeth, known as cestracionts, and the cochliodonts (Fig., below). The acanthodians vanished with the Paleozoic, while the other forms were very sparingly represented after Permian time.

Land Life. — Of Waverlian land life little is known other than plants, and most of these are preserved in the Pocono deposits of the Appalachic trough. The plants are so like those of the Pennsylvanian that a description of them is deferred to Chapter XXVII.

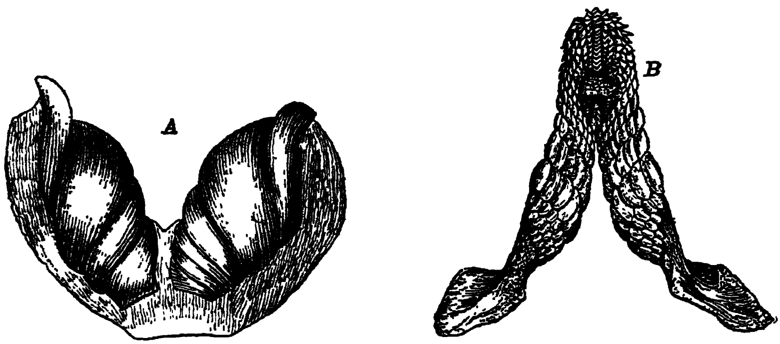

Fig. 118. — Cochliodont (*A*) and cestraciont (*B*) teeth of primitive sharks. *A*, jaw with two large tooth-plates (*Cochliodus contortus*). *B*, upper jaw, with many teeth, of Port Jackson shark (*Cestracion philippi*). British Museum (Natural History).

Of fresh-water fishes, other than those of the Albert formation, little is known in the Waverlian deposits, but those of Europe indicate a marked decline of the stocks seen in Devonian time.

Toward the close of Tennesseian time, throughout the continental deposits of Pennsylvania known as the Mauch Chunk are seen the tracks of many kinds of amphibians, nearly all of which are still undescribed. Lea in 1849 collected a most interesting slab, a little over 5 feet long, with six successive foot impressions made by an amphibian (*Palæosauropus*) with a 13-inch stride. This slab is ripple-marked and has rain imprints, indicating a mud flat of land origin, over which the animal walked when the deposit was yet soft and wet. Another amphibian track has been found in Giles County, Virginia (*Dromopus*).

Climate of Mississippian Time

The marine life of Mississippian time appears to indicate warm and equable waters throughout North America, though the seas were never warm enough to produce great numbers of corals or coral reefs, nor were the cephalopods ever present in great variety.

On the land the organic evidence of Waverlian time is very scant but since the continental and brackish-water deposits are of darker colors and the coal beds thin and local (Pocono), warm and moist conditions seem to be indicated. During Tennesseian time the evidence of the sediments brings out the further fact that the mild climate of the land became more and more semiarid and locally even arid. This condition was especially true for the area to the north and northwest of the Acadian and Appalachian mountains, as evidenced by the thick and widely spread red deposits (Mauch Chunk) of Pennsylvania and West Virginia, the red beds of Michigan with salt, the thick red Windsor formation of Nova Scotia with its deposits of gypsum, and the thick red fresh-water conglomerates of Gaspé (Bonaventure). Toward the close of the Tennesseian the climate became cooler, and in the mountains of Nova Scotia there appear to have been even winters.

Mountain Making of Mississippian Time

We have already directed attention to the renewal of crustal warping toward the end of the Waverlian, and now at the close of the Tennesseian the evidence is clear that folding took place in several parts of North America and on a great scale.

Ouachita-Cahaba Disturbance. — In the southern Appalachic geosyncline of central Alabama (the Cahaba coal field), Butts reports at least 10,000 feet of coarse deposits, conglomerates and sandstones, that in the main are of continental and brackish-water origin, and all of which are referred to a Pennsylvanian age "older than the Pottsville." A similar series (Stanley-Jackfork), having a maximum thickness of over 12,000 feet, was laid down along the south side of the Arkansas valley, extending into southeastern Oklahoma, that is, in the area of the Ouachita (pronounced watch-i-tah) Mountains. These great thicknesses of detritals of earliest Pennsylvanian time show that in southwestern Appalachis and in northeastern Llanoris mountains of no mean altitudes had been in existence. The Wichita Mountains of western Oklahoma were also folded at this time. These orogenic movements, resulting in a greatly changed geography of the Central Interior seas, and a

consequent long emergent time, separate the Tennesseian from the Pennsylvanian.

The Ouachita-Cahaba disturbance finally completely blotted out the Mississippi embayment that had been in existence since Lower Cambrian time, and warped markedly the Central Interior region, so that the pattern of the middle and late Pennsylvanian seas is very different from that of earlier times (see Pl., p. 355).

Windsor Disturbance. — In Nova Scotia and New Brunswick, the Cheverie and Windsor series of about 2000 feet in thickness and all of the older formations were toward the close of the Tennesseian folded into a high series of mountains. Bell (1921) holds that this was the most marked of four crustal movements occurring during the Carboniferous in the Maritime Provinces (see p. 369). All of the Pennsylvanian strata lie unconformably upon the older formations, and the Coal Measures, wholly of continental origin, attain very great thicknesses (14,000–18,000 feet). Clearly such great piles of intermontane deposits indicate previously made mountains of considerable altitude. The New Brunswick geanticline, extending into the New England States, was also reëlevated.

Variscian Mountains of Central Europe. — In many parts of western Europe, and especially in Germany, all of the formations beneath the Coal Measures are folded and over them lies unconformably the Upper Carboniferous. The time of this folding was after the Culm and before the introduction of the productive coal measures. A high chain of mountains then extended through middle Germany and for this reason is sometimes spoken of as the German Middle Mountains. These mountains occur in the area of the ancient peoples known as the Variscians, and they appear to be the European equivalents of the Canadian mountains of late Windsor time.

Collateral Reading

J. Barrell, Origin and Significance of the Mauch Chunk Shale. Bulletin of the Geological Society of America, Vol. 18, 1907, pp. 449–476.

Charles Butts, The Southern Part of the Cahaba Coal Field, Alabama. United States Geological Survey, Bulletin No. 431, 1911.

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H. S. Williams, Correlation Papers — Devonian and Carboniferous. United States Geological Survey, Bulletin No. 80, 1891.

H. S. Williams, What is the Carboniferous System? Bulletin of the Geological Society of America, Vol. 2, 1891, pp. 16–20.

CHAPTER XXVI

SPINY-SKINNED SEA ANIMALS (PHYLUM ECHINODERMA)

As the American seas of Mississippian time, and especially during the Waverlian epoch, swarmed with a great variety of crinids, blastids, and echinids, it is desirable that these classes of animals be described here.

General Description. — In the seas and oceans there is a great variety of radiate animals called echinoderms, which means *spiny skin,* a name given because their outer surface is usually more or less studded with parts composed of carbonate of lime in the form of spines and plates. These hard pieces may consist of small particles loosely dispersed in the skin, or occur in the form of spines that make a loose or open mesh, or entirely encase the soft parts in a firm skeleton, a mosaic of closely adjoining plates that are either plain or studded on their outer surface with more or less long spines. In large species (pentacrinites) of the Mesozoic there may be even more than three million stony pieces.

The parts of the body are usually arranged on the plan of five divisions, five radii and the same number of spaces between them — the interradii — being characteristic of the echinoderms. These parts are best seen in the starfishes; while they are present in nearly all Echinoderma they are at times much obscured.

The Echinoderma are divided into two great groups on the basis of their leading a free or sedentary life. The *free* forms having fossil representation are the starfishes (including the brittle stars) and the echinids. The sedentary or attached, *stalked* kinds are the crinids and blastids, among which nearly all the fossil forms are characterized by having a more or less long, jointed stalk by which they are, as a rule, fixed to the ground. In the free forms (Eleutherozoa), the mouth is on the under or ventral side, and it is on this side that they crawl about in search of food. The stalked forms (Pelmatozoa), however, are turned over and have the mouth and the ventral surface upward, while from the center of the back or dorsal side originates the stalk, which is usually fastened to the sea bottom. All of the forms that are attached or sessile feed on microscopic food taken out of the circulating sea water. Most of the Echinoderma have the power to reproduce parts bitten off by predatory animals,

and a starfish may be torn into several pieces and each piece, under favorable conditions, will regrow the lost parts, because an arm retaining a part of the disk has all the essential organs of an entire starfish. The starfishes have little significance in Historical Geology and need not be described here.

Echinids or Echinoidea. — These are the sea-urchins, sand-dollars, and heart-urchins, and, as a rule, are extremely spiny, many of the spines being movable on ball-and-socket joints. In general form, the echinids are dome-shaped, the wall of the dome being made up in living forms of twenty columns of closely adjoining plates arranged in pairs (see Figs. *B* and *C*, below). Five pairs of these are the *ambulacral columns* which are perforated by tube-feet, and alternate with five other pairs which are not perforated, the *interambulacral columns*. The mouth is on the lower or flatter

A *B* *C*

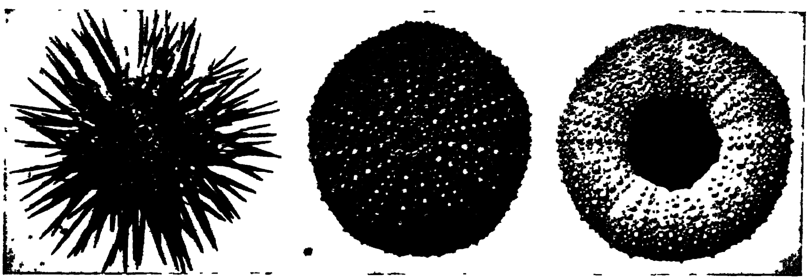

Fig. 119. — Skeletons of two kinds of living sea-urchins (Regularia). *A*, purple sea-urchin (*Arbacia punctulata*), with all its spines, from dorsal side, × ½. *B*, *C*, common sea-urchin (*Strongylocentrotus dröbachiensis*) stripped of its spines to show corona from dorsal and ventral (mouth) sides, × ½. After Coe, Connecticut Geol. Surv.

side and is often provided with a powerful jaw of very complicated structure, first described by Aristotle and compared by him to a Greek lantern, and hence now referred to as "Aristotle's lantern."

At the top of the dome or corona is the anal opening, around which are arranged ten plates in one or two circles. The five large plates of the inner ring are called the *genitals* because each is pierced by an opening, the terminus of the genital organs. The five smaller plates of the outer ring, situated at the termini of the five pairs of ambulacral columns, are known as the *oculars* because in them are located the so-called eyes (see Fig. *B*, above, but here the plates are arranged in a single ring. Also see Fig. *C*, p. 347).

The echinids just described are called *regular echinids* because they are the normally constructed forms, but in the seas of to-day

there are many others whose structure is less normal and which are known as *irregular echinids.* Their irregularity consists in that the anal aperture is not at the top of the dome but on the posterior ventral surface (see Figs., below). Further, they are not circular in outline but are somewhat elongate, often lobate and heart-shaped, and hence are called heart-urchins. The sand-dollars are also of the irregular type. The spines in these forms are very short and slender and usually there is no lantern-like jaw.

The echinids described above are practically unknown in the Paleozoic rocks, but, appearing in the earliest Mesozoic, become more and more varied and are of much importance in Historical

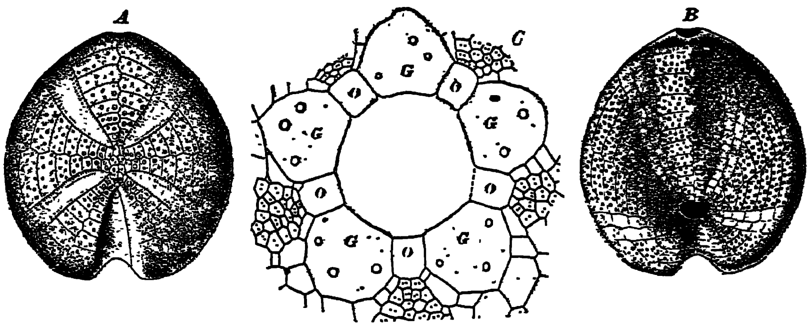

Fig. 120. — *A* and *B*, fossil heart-urchins (*Cardiaster cinctus*) from the Upper Cretaceous of New Jersey (Irregularia). Note that here the anal opening is not in the position of that in the Regularia. *A*, from dorsal, and *B*, from ventral side. After W. B. Clark, U. S. Geol. Surv. *C*, enlarged apical disc of the melon echinid (*Melonechinus multiporus*), from the Upper Mississippian. showing three openings in each genital plate (*G*), and the ocular pieces (*O*). After Jackson.

Geology. This is particularly true for Europe, where the Mesozoic strata are at times crowded with them, but in America they are always rare except in the Lower Cretaceous beds of Alabama, Texas, and Mexico. About 2500 fossil forms are known, and some 500 living kinds.

Paleozoic Echinids. — The Paleozoic echinids differ from those described above in having as many as seventy-five columns of plates in the corona (Pl., p. 337, Fig. 5). Here the ambulacral areas have from two to twelve rows and the interambulacrals from three to eleven. Further, the plates usually overlap like the shingles on a roof. These forms appeared in the late Silurian but were not common until the Mississippian, when the melon echinids (*Melonechinus*) were characteristic.

Crinids or Crinoidea (means *lily form*). — The crinids are popularly known as sea-lilies or stone-lilies, names that give very erroneous suggestions as to their nature, since they are animals and not plants. A better name is *feather-stars*. They are Echinoderma which are usually gregarious in habit and nearly all of the fossil forms are fixed to the sea bottom by a more or less long stalk; after the Paleozoic there are, however, also many free forms that crawl or swim around. In the present seas, A. H. Clark says there are living upward of 575 species in 142 genera, and of these 500 are unstalked. About one half of the living forms occur in shallow seas. From these facts it appears that crinids are not on the verge of extinction, as is sometimes held, since they are in places exceedingly common. They feed on microscopic plants and animals.

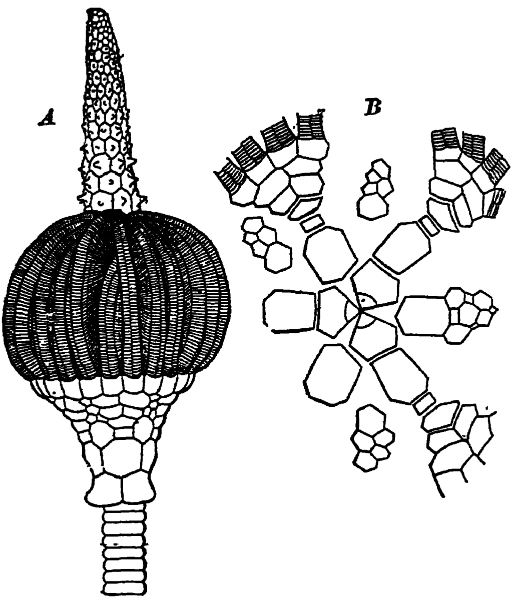

Fig. 121. — A box crinid (*Batocrinus pyriformis*) from the Mississippian of Iowa. *A*, stalk, calyx, arms, and anal tube, from the side. *B*, plates of calyx spread out to show shape and arrangement. After Keyes, Geol. Surv., Missouri.

Crinids consist of three main parts: (1) the *calyx* or body proper, (2) the *arms*, and (3) the *stalk*. The calyx and arms together are referred to as the *crown* (see Fig., above, also Pl., p. 239, Fig. 5, and Pl., p. 270, Fig. 4). The calyx may be large or small and is made up of a variable number of closely adjoining plates, which are arranged in a very definite manner in the different forms, and the crinids are classified according to their arrangement — a scheme too complicated to describe here. From the upper part of the calyx arise the arms or radii, hardly ever less than five in number, and these may fork once or many times according to a regular or irregular plan, but most often in multiples of five. The arms are made up of single or double columns of plates and may have a regular series of small armlets arising from their inner edges and known

as *pinnulæ*, suggesting the barbs on a feather (hence the name *feather-stars*). The ambulacra are situated along the inner sides of the arms and pinnulæ, where the microscopic food is captured and conveyed to the mouth at the top of or within the calyx. The *anal aperture* is also on the upper or ventral surface of the calyx but is always more or less eccentrically situated and often drawn out into a long anal tube (Fig. *A*, p. 348). The stalk consists of many superimposed, disc-like, perforated pieces called columnals. It is usually short, from 6 to 18 inches in length, but in one Jurassic form attains 50 feet.

Ancient Crinids. — In the Paleozoic, crinids at times were very common, especially the forms known as the box crinids (Camerata, now extinct). In these, the calyx was large and box-like, with thick plates that usually held together tightly (see Pl., p. 337, Figs. 10, 11). Their remains are sometimes so common as to make thick crinid limestones, this being especially true in the Mississippian formations.

Crinids appeared early in the Champlainian but are not common fossils until the Silurian, when they are plentiful, and remain so until near the close of the Paleozoic era. The crinids of the Mesozoic are less abundant and in American deposits are indeed very rare. They are very different from those of earlier times and more like those inhabiting deep water to-day. In Europe, crinids are common in the Triassic and Jurassic.

Blastids or Blastoidea (means *germ* or *bud*) are small, stalked, extinct Echinoderma that arose in early Champlainian time. In a broad way, these fossils resemble nuts and because of this the people in the southern states, where they are common, often call them "fossil hickory nuts" (*Pentremites*). We may say they are far simpler than the crinids, and differ markedly in having no arms, only delicate armlets called brachioles. These are situated at the sides of the five large and conspicuous ambulacral areas seen on the sides of the calyxes, areas which are practically never seen in crinids. In blastids the calyx is usually made up of thirteen plates (see Pl., p. 320, Figs. 1-3; Pl., p. 337, Figs. 6, 7).

Blastids appeared in the Champlainian, and, while often seen in Devonian strata, were not common in America until Mississippian time, when the seas abounded in them. They are guide fossils of this time, but died out early in the Pennsylvanian.

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CHAPTER XXVII

THE PENNSYLVANIAN PERIOD, THE TIME OF GREATEST COAL MAKING

History. — The term Pennsylvanian embraces the Coal Measures of the older geologists. The succession of strata included under it was first determined in Pennsylvania by Henry D. Rogers for the United States Government in 1838. Then and for a long time afterward they were referred to as the Coal Measures, or the Upper Carboniferous. Finally, in 1891, H. S. Williams applied to them the term Pennsylvanian Series as a period name, and this geographic name has come into general use for the older coal-bearing rocks of North America. The period takes its name from the Keystone State, whose coal measures in 1918 yielded almost half ($800,000,000) of the country's coal output.

Significant Things about the Pennsylvanian Period. — The outstanding facts about the Pennsylvanian are its variable geography, resulting in great coal-making swamps, and its abundance of land plants. Not only were the marine and the fresh waters fully inhabited, but the lands were peopled with breathers of the air in plenty, from plants, snails, and insects to amphibians and reptiles. It was still a very ancient organic world, but the prophecy of medieval times was upon it and its unfolding was to begin in the next or Permian period.

The climate of Pennsylvanian time was warm and genial the world over, and the lands bordering the epeiric seas were moist, with an abundant and well distributed rainfall. The seas, due to the marked instability of the earth's surface during this period, oscillated back and forth over the low lands more actively than before. As a consequence there developed great fresh-water swamp areas replete with a varied flora, which grew quickly and reproduced itself in the main through spores. The plants were buried in the swamps where they had lived, and they accumulated in such vast quantities as to make the greatest of the world's coal reserves.

Pennsylvanian time was especially one of crustal unrest. Previously during the Paleozoic the times of mountain making occurred

at or toward the close of the periods, but during the Pennsylvanian the mountains were raised repeatedly after long pauses of stability. This greater crustal unrest is also the prophecy of a coming marked climatic change along with larger and higher lands. The previous warm and moist climate finally gives way to trying ones of aridity and wide glaciation. The old organic habitats are undone, and with

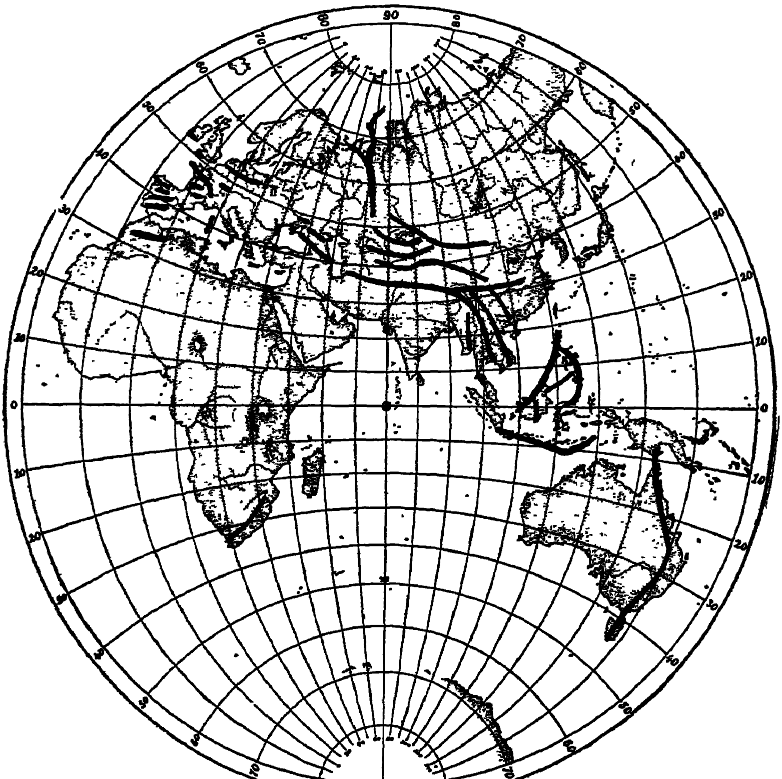

Fig. 122. — Stereographic map of the eastern hemisphere, after Penfield, showing the Altaids (including the Paleozoic Alps of Europe), mountain ranges formed toward the close of the Paleozoic. Somewhat altered from J. W. Gregory, after E. Suess.

their passing comes a revolution in the organic world that drives it into a higher evolution of better adapted land plants and animals. Henceforward the struggle for the mastery of the lands lies with the more alert Permian reptiles, and some of them, overrunning the dry land, evolve either into the ponderous dinosaurs or the small birds and mammals of Mesozoic time.

TABLE OF PENNSYLVANIAN FORMATIONS

Eastern Areas		Kansas		Oklahoma-Arkansas	Eastern Texas	W. Texas
Dunkard of the Permian period *General retreat of seas in east*						
Upper Pennsylvanian Monongahelan Productive upper coals Ouralian (marine) } of Europe Upper Stephanian } of Europe		Wabaunsee Shawnee	Missouri	Ralston Pawhuska	Cisco	Gaptank
Seas begin to retreat		Douglas	Missouri			Gaptank
Middle Pennsylvanian Conemaughan Usually barren of coal Lower Stephanian of Europe	Ames li. of Penn.	Lansing Kansas City Pleasanton	Missouri / Des Moines	Wewoka	Upper Canyon	Tesnus-Dimple-Haymond
Greatest spread of seas		Altamont	Des Moines	Wetumka		Tesnus-Dimple-Haymond
Alleghenian Productive lower coals Upper Moscovian-Westphalian of Europe	Linton of Ohio Freeport coals Kittanning coals (Morse's Ck., Ill.) Clarion coals	Pawnee Fort Scott	Des Moines	Calvin Senora-Stuart	Lower Canyon	Tesnus-Dimple-Haymond
Lower Pennsylvanian Pottsvillian Productive coals Lower Moscovian of Europe Namurian-Waldenburgian	Kanawha Mercer-Nuttall Sewell-Sharon Raleigh-Bonair Lower Lykens-Pocahontas coals	Cherokee	Des Moines	Thurman Boggy 3000′ Savanna 1500′ McAlester 2800′ Atoka-Winslow 7800′ (Boggy to Atoka-Winslow: Glenn up to 15,000′)	Strawn Millsap Break	Tesnus-Dimple-Haymond
Spread of seas						
Lowest Pennsylvanian Bendian Barren of coals *Complete break with Mississippian*		Break	Cahaba of Ala.	Upper Caney Morrow-Wapanucka 800′ Lower Caney Jackfork 6600′ Stanley 6100′	Smithwick shales 0-1000′ Marble Falls li. 200-700′ Lower shales (Bendian)	Break

Events in North America

Submergences. — The geologic history of the interior or basin-like part of North America during Pennsylvanian time was one devoid of crustal folding, although local warpings were common, resulting in periodic shallow-water submergences. In the New England States and the Maritime Provinces of Canada, however, the geanticlines were raised vertically, and here mountains were made at different times. The crust was also folded in the southern states of the Central Interior region (chiefly Arkansas, Oklahoma, and Texas), and finally, toward the close of the Pennsylvanian, all of these areas, besides the Appalachians and the southeastern part of the Rocky Mountains, were in the throes of mountain making. These movements will be described later and they are mentioned here only to emphasize the fact that the greater medial portions of North America, and chiefly the United States, were a region of crustal warpings only. Into the down-warped areas the waters of the Pacific entered.

The seas submerged great parts of the continent, coming from the south and west over Texas and Oklahoma and overlapping the land northward into Nebraska and chiefly eastward into Pennsylvania. For a long time the seaways were small and restricted to Texas, Oklahoma, and Arkansas, and long before the submergence became general, three fresh-water deltas were forming, one centering about Pottsville, Pennsylvania, another about the Kanawha River, West Virginia, and the third in the area of the Cahaba Valley of Alabama. Finally these areas also came under the influence of the spreading seas at or before the close of Pottsvillian time. The submergence was most extensive in late middle Pennsylvanian or Conemaugh-Canyon time, when about 30 per cent of North America was again under the sea. It should be said, however, that during the last half of Pennsylvanian time, the sea-level was again decidedly oscillatory, due to local warpings of the land, for the Coal Measures are largely a series of interbeddings of shallow marine and brackish-water finer sediments with coarser ones of fresh waters. A final regression of the seas began late in this period, and they lingered longest west of the Mississippi and south of the Missouri rivers, retreating more and more to the southwest in very latest Pennsylvanian time, a retreat that was continued, also in an oscillating manner, throughout the Permian.

Great Coal Deposits. — The most striking feature of the Pennsylvanian or Coal Measures in North America and Europe is the fact

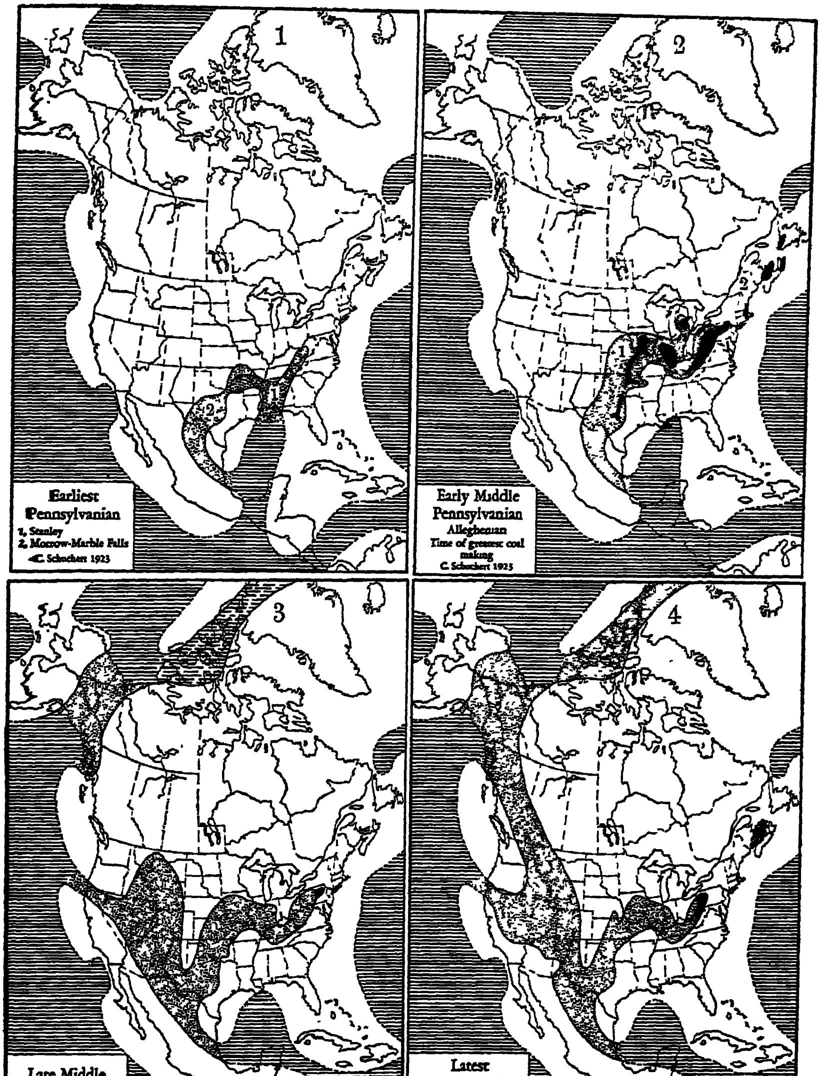

Plate 24. — Paleogeography of Pennsylvanian time.

Epeiric seas dotted; oceans ruled. Fresh-water deposits cross-ruled; coal-making swamp areas in solid black. Note that the latter are in areas of the seas (1 = paralic coals), and in fresh-water basins of deposits (2 = limnetic coals).

Note the vanishing of the Appalachic geosyncline, and the spreading of the southern Cordilleric trough across Mexico. The former change is prophetic of the rising of the Appalachian Mountains, illustrated in Plate 32 (p. 425).

that they contain the greatest known accumulations of coal. This has long been recognized and it led the older geologists to name the period the Coal Measures. It is true that much coal was laid down subsequently, and especially during the Permian, Jurassic, Cretaceous, and Cenozoic, but at no other time was so much valuable fuel deposited as during the Pennsylvanian. The great coal fields of China, according to the latest work of the Japanese and Chinese geologists, are probably all of Permian age. Because the nature of coal and its mode of formation are of such great importance to humanity, a special chapter will be devoted to them, and another one will describe the coal flora; in this chapter we shall present only a general statement of the main events and life characteristics of Coal Measures time.

Character and Significance of Deposits

In the *Maritime Provinces* of eastern Canada the Pennsylvanian is well developed and usually of very great thickness. The celebrated Joggins section of Nova Scotia is 13,000 feet in depth and consists entirely of continental deposits. The Cape Breton series is 10,000 feet thick and the Pictou field has a similar thickness. The Riversdale and Harrington beds (with marine zones) and the plant-bearing strata ("fern ledges" of fresh-water origin) near St. John, New Brunswick, are also of Pennsylvanian age. It is very rare for marine fossils to be reported from this region, and the few that have been found indicate early Pennsylvanian time. On Prince Edward Island the Permo-Carboniferous has an exposed thickness of over 6000 feet and consists of soft reddish shales and sandstones.

In the *Appalachic basin* east of the Cincinnati uplift, and in the greater *Central Interior sea* to the west of this axis and extending into Nebraska, Kansas, Oklahoma, and central Texas, the formations have alternations of marine deposits with coal accumulations (see Pl., p. 355). It was in these areas, therefore, that the sea-level was most oscillatory, and here the workable coals occur. In the Central Interior basin the coals are associated with more normal marine faunas and are interbedded with calcareous shales and limestones, this generalization applying in the main to the western side of the Cincinnati axis, and less to the eastern side. In the Appalachic basin the mass of strata is not only thicker but also coarser, consisting, in general, of sandy shales and sandstones with the marine and calcareous zones inconspicuous or, locally, even absent, the marine zones vanishing eastward. Here also the coal accumulations are

thicker, as the swamps were of greater areal extent and less often under the influence of the sea.

The essentially muddy and sandy deposits of Pennsylvanian-Permian time in eastern Kansas have a united thickness of about 4600 feet, thinning into Nebraska and Iowa but thickening greatly southward. To the south, the Cherokee dark shales change completely, passing more and more into a tremendously thick series of sandstones and sandy shales. To the south and southeast, there then lay a high land of large dimensions known as Llanoris, of which the Sabine uplift of Louisiana is a part. This is the land from which the sediments came, for Ozarkis and the rising Arbuckles and Wichitas were too small to have furnished the great thicknesses of the Pennsylvanian deposits of the south central area. West of Little Rock, Arkansas, into southeast Oklahoma occurs the thickest series of Pennsylvanian strata known anywhere in the world, with a depth of between 20,000 and 25,000 feet.

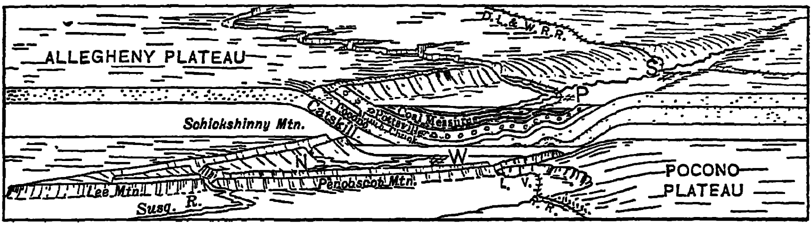

Fig. 123. — Block diagram of the Scranton, or northern anthracite synclinal coal basin, the largest in eastern Pennsylvania. *S*, Scranton; *P*, Pittston; *W*, Wilkesbarre; *N*, Naticoke. After A. K. Lobeck.

Fully 15,000 feet of these are as old as, or older than, the Cherokee shales, and below them lie other similar strata (Jackfork and Stanley) that attain a like thickness. We may add here that there are in the basal portion of the Stanley series from three to five tuff beds, each of which is from 6 to 85 feet thick, showing that active volcanoes were in existence nearby. The general thickness along the south side of the Arkansas valley H. D. Miser tells us is between 20,000 and 25,000 feet, of which fully 90 per cent is coarse clastic material. As one proceeds to the north and west and away from Llanoris, the lower half of this mighty pile, the débris of worn-down mountains, thins very rapidly and changes into dark muds and even into limestones of no great thickness (Caney shales up to 1500 feet, Morrow-Wapanucka limestones and shales up to 800 feet, and the equivalent of these in Texas, the Bendian series of limestones and shales, 400–1900 feet).

There is as yet no harmony among stratigraphers as to the age of the series called in this book Bendian. The reason for this lack of decision is the general absence of fossils, and when such are present the animal remains are usually of black shales and therefore of long-ranging forms. They are therefore not diagnostic for detailed correlations, and even though the plant remains are by far the more significant, they are scant in quantity and appear to lack the proof of geologic

age that would be theirs if the American Mississippian had had a long and abundant sequence of floras. Hence we are dependent as yet in the main upon the field relations, but unfortunately the area is highly disturbed by folding and faulting; further dependence is had in the principle that a great series of clastics are indicative of new mountains that have arisen toward or at the close of a period.

After the above was written, Charles W. Honess showed the writer a series of fossils collected by him from the top of the Jackfork formation. These are clearly of Morrow-Wapanucka affinity. It is therefore held that the Jackfork series is the equivalent of the upper Caney shales and that all of these formations agree in age with the Bendian series of Texas. All are older than the usual type of Pennsylvanian formations.

In general, the series is an alternation of shale and sandstone, for the calcareous deposits of Kansas thin southward while the sandstones of Oklahoma vanish northward. Furthermore, the fossiliferous marine condition of these beds in Kansas gradually vanishes more and more toward Oklahoma, and the greater part of the higher series changes into the widely known *red beds* of that state, Texas, and the southern Great Plains country (see Pl., p. 355, Fig. 4). With the appearance of the red deposits not only do the marine fossils disappear, but tremendously thick beds of table salt and gypsum occur. In western Texas, 2000 feet beneath the surface, there is also much potash. On going south in Texas, the amount of gypsum becomes less, the red beds yield very interesting amphibian and reptilian remains, and the time is toward the close of the Pennsylvanian or is Permian. It is apparent, then, from the above paragraphs, that the seas retreated at first in the east and north, and we shall see that the continuing Permian waters vanish more and more to the southwest. Study maps on pages 355 and 425.

Since petroleum is of organic origin, and chiefly from plants, it is but natural that the Coal Measures should also abound in oil. In the mountain areas this volatile substance has long ago been dissipated through the folding and fracturing of the Pennsylvanian strata. In the Ohio and Mississippi valleys, petroleum is also not abundant, possibly because these same strata are at the surface, permitting the gases and oil to escape into the air. But in the "Mid-Continent Oil Fields" of Kansas, Oklahoma, and north central Texas there are tremendous riches of these hydrocarbons. In Kansas, the pools occur mainly in the deep-lying Mississippian, and in Oklahoma and Texas at various levels in the Pennsylvanian. For other detail, see Chapter XX.

In the *Cordilleran region*, the record is very different from that of the eastern portion of the continent. In the area of the Rocky

Mountains and the Great Plains, wherever Pennsylvanian formations are known, they are as a rule of normal marine waters, and consist chiefly of limestones and calcareous shales, with local sandstones. Rarely is there an alternation of this condition with that of coal making, such as is found in the central and eastern parts of the country. Coal beds are known, however, in many places in eastern New Mexico and Utah, and in western Colorado, but the coals are thin and have but little commercial value. They occur at the base of this Pennsylvanian, and represent the introductory swamp conditions before the area was wholly submerged by the invading seas. In general it can be said, therefore, that the Pennsylvanian of the Cordilleran region is made up in the main of limestones and calcareous shales, with but little sandstones, contrasting in this very markedly with the Pennsylvanian of eastern North America.

Along the entire *Pacific area* from northern California into arctic Alaska, the limestones and calcareous shales of the Pennsylvanian and the early Permian are interbedded with much extrusive igneous material. The thickness in California is not less than 4600 feet, with a maximum of 10,000 feet, while in the Copper River region of Alaska it is nearly 7000 feet. The calcareous deposits often abound in fossils unrelated to those found elsewhere in North America; they are of the Pacific, and seemingly of the northern Euro-asiatic, realm, while the life record of the eastern Cordilleric seas is of more southern Pacific, and seemingly also of Caribbean, waters and closest in relationship to those of South America; in the main it is best regarded as constituting the North American province.

Life of the Pennsylvanian Period

Cosmopolitan Land Floras. — We have seen in earlier chapters that plant combinations or floras are not known earlier than the Middle Devonian. Although their description is deferred to a later chapter, it may be stated here that with the Pennsylvanian, land plants began to be common in America, and that the swamp floras were then luxuriant, large, and varied. Furthermore, these floras, and the land animals as well, were not only very much alike in the different lands of the northern hemisphere, but there was a marked similarity even between the floras of the two hemispheres during the greater part of Pennsylvanian time (see Fig., p. 360). In other words, the floras, and to a lesser extent the faunas, were cosmopolitan, and their similarity was undoubtedly due to equable climates and easy migration across the extensive east-west continent

Fig. 124. — Pennsylvanian flora and amphibia, as restored by J. Smit. In the background are *Sigillaria*, with tree-ferns and conifers in the middle distance. In the foreground are *Calamites* and seed-bearing fern-like plants. Amphibia are represented by a small four-limbed microsaurian (*Keraterpeton*), a large-headed form (*Loxomma*), and a snake-like, gill-bearing stegocephalian (*Dolichosoma*; from Linton, Ohio). From Knipe's *Nebula to Man*.

Eris. Their distribution was further facilitated by the fact that most of the plants had *spores*, or microscopic reproductive germs, which could be widely blown about by air currents (see Pl., p. 377, Figs. 4–6).

The late Mississippian flora, according to David White, was impoverished, restricted, and stunted, and yet out of this unpromising assemblage came the Pennsylvanian succession. Early in the Pennsylvanian (early Middle Pottsvillian) the flora had expanded and differentiated largely, with a further rapid expansion a little later (through the Pottsvillian into early Alleghenian time). Still later (Conemaughan) most of the gigantic lepidodendrons vanished, along with a great reduction of the spore-bearing plants. Toward the close of Pennsylvanian time (Monongahelan), the seed plants began to differentiate rapidly and to displace the spore-bearing forms. It was then that the first distinctly cycadaceous plants appeared.

Insects. — According to Handlirsch, the Viennese authority on fossil insects, there is no evidence of these animals older than the Lower Pennsylvanian. However, there is good ground for believing that they may have arisen in the Devonian (see Pl., p. 363).

The Pennsylvanian was the time of giant insects, the largest ever known. The maximum size was reached by those of the dragon-fly type, one of which, found in the Coal Measures of Belgium, measured 29 inches across the wings. Out of four hundred forms known from the Lower and Middle Pennsylvanian, all but one had a wing length of over 0.38 inch, while more than twenty had a length of 4 inches, six attained to nearly 8 inches, and three to 12 inches or more, the average being 2 inches. In the earliest Permian there were also large forms, but soon afterwards began a decline in size which continued throughout the Permian and Triassic and culminated in early Jurassic time. At no period since the Pennsylvanian have insects grown so large, and their rapid decrease in size after the Pennsylvanian can only be connected with the drier and colder climates of Permian and Triassic times.

The Pennsylvanian well deserves its title of the *Age of Cockroaches*, since more than eight hundred kinds are known from rocks of this period (Pl., p. 363, Figs. 3, 4). They were mainly carnivorous, and as a rule large, several attaining a length of 3 to 4 inches. While no species were common to America and Europe, their resemblances are marked, indicating an easy land passage from one continent to the other.

There are now known about 1300 species of insects from the Pennsylvanian and Lower Permian strata. They are still scarce in the Lower Pennsylvanian, but in the middle and upper thirds of the system are common. The oldest forms, known as Palæodictyoptera (170 kinds), were especially prevalent in the Pennsylvanian, and all died out during the Permian (see Pl., p. 363, Figs. 1, 2). They were, as a rule, large in size and of primitive structure, and led an amphibious life, their youngest or larval stage being spent in the water. In general, they were not carnivorous animals, but as they had powerful chewing mouths it is thought that they fed on plants and on sluggish or dead animal matter. They had four straight wings, all alike, which projected sideways like those of the modern dragon-flies and could not be folded back over the abdomen as in most modern insects. The thorax had three large segments, followed by a long and slender abdomen in which the segments were alike, ending in two long cerci or appendages connected with the breathing organs, as in the living may-flies. Their eyes were compound and their antennæ simple.

These primal insects gave rise to several transitional stocks, which in turn changed into the modern insects, such as the dragon-flies (Odonata), cockroaches (Blattoidea), and grasshoppers (Orthoptera).

Scorpions and Spiders. — In the Pennsylvanian are found scorpions, which, ancient as they are, much resemble those of modern times. Associated with them we see many forms of rather stout spider-like animals, having a distinct cephalothorax (head-trunk), and usually a large abdomen, the latter with four to nine segments; in none of them, however, are known anal spinnerets, or organs for the making of webs (see Pl., p. 363, Fig. 5). Those with smaller abdomens, and therefore nearer the true spiders, also occur in the Pennsylvanian rocks, but are very rare fossils.

Thousand-legs or Myriapoda appear in the Lower Devonian (Old Red of Scotland) and are plentiful in association with the Pennsylvanian floras of America. The average species was about 2 inches in length, but at Mazon Creek, Illinois, there lived one that had a length of about 12 inches and was 0.75 inch thick. All had double pairs of legs. The head was large, and had great lateral compound eyes, in some of which there were a thousand lenses. In habit some at least were amphibious, and others appear to have been completely adapted to the land.

Land Snails. — There is no evidence of air-breathing or land snails until Middle Pennsylvanian time. The greatest number of individuals have been taken by Dawson from the hollows of fossil tree stumps (*Sigillaria*) at South Joggins, Nova Scotia. All of the species are small.

Fresh-water Clams. — In many of the coal areas, in dark, very fine-grained shales, both in North America and more especially in western Europe, are found great quantities of small and large bivalves (*Carbonicola*, *Anthracomya*, and *Naiadites*) which suggest living river and lake shells (*Unio*, *Anodonta*, *Dreissensia*). It is therefore certain that the rivers at least since Pennsylvanian time have been stocked with an abundance of living food for fishes.

Land-living Vertebrates. — In the Pennsylvanian deposits there is much evidence of the presence of many kinds of Amphibia (forty-

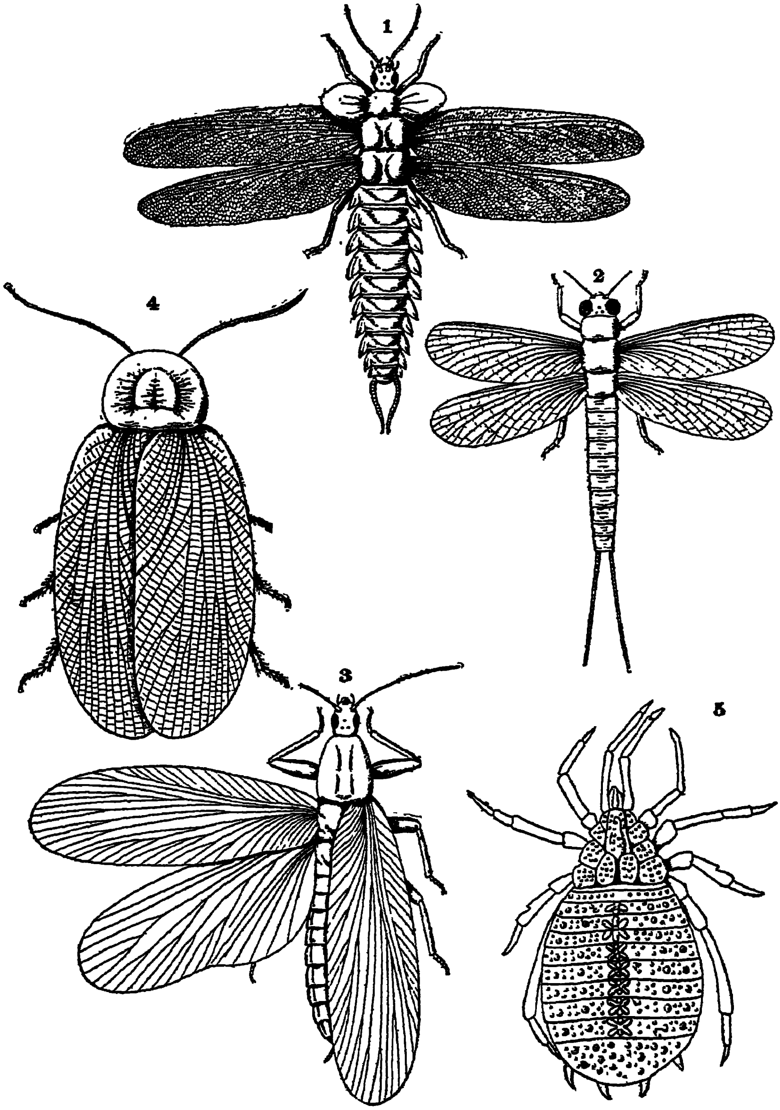

Plate 25. — Pennsylvanian primal insects or Palæodictyoptera (1, 2), ancestral cockroach (3), true cockroach (4), primitive spider (5). The original of Fig. 1 had a spread across the wings of 29 inches.

Fig. 1, *Stenodictya lobata;* 2, *Eubleptus danielsi,* $\times 1\frac{1}{3}$; 3, *Eucænus ovalis;* 4, *Aphthoroblattina johnsoni,* $\times \frac{1}{2}$; 5, *Eophrynus prestwichii,* $\times 1\frac{1}{2}$. Figs. 1–4 after Handlirsch.

six genera) and their bones become increasingly more abundant in the strata of later times, as described in Chapter XXX. The Amphibia are most common in the Pennsylvanian, and their origin goes back to at least the Middle Devonian. The remains of Reptilia, on the other hand, which dominated the land of Permian time, appear first in the Upper Pennsylvanian (see Pls., pp. 407 and 413).

At Linton, Ohio, occurs the Freeport coal of the Alleghenian series, and beneath this humic coal is found a thin local deposit of cannel coal. This is the first material laid down in an open fresh-water pool in an extensive swamp in which the coal flora grew and accumulated. In the cannel coal has been found an abundance of ganoid fishes and over fifty species of flesh-eating amphibians (Stegocephalia). They range from 6 inches up to 10 feet in length, and nearly all of them are known only from this place — a limited glimpse of what must have been a highly varied and prolific amphibian fauna. Curiously, almost no other animal life is preserved. (See Fig., p. 360.)

The very varied amphibian fauna of the coal swamps, summarized by Moodie, contains representatives of no fewer than seven orders, nineteen families, forty-six genera, and eighty-eight species. They are therefore seen to be a highly varied group of land animals, ranging in size from less than 2 inches in length to as large as an adult Florida alligator. Most of them, however, were small creatures related to the living salamanders, but being more primitive, are known as branchiosaurs and microsaurs. They were rather sluggish animals, living about or in the water, as is indicated by the known larval stage of branchiosaurs. They were more or less protected against their enemies by an external body armor, and because of this are also known as stegocephalians (from the Greek word meaning *cover* and *head*) to distinguish them from the salamanders. They had their best days in the Pennsylvanian, and their further evolution will be discussed in the chapter on the Permian period.

Life of the Seas. — The invertebrate marine life of Pennsylvanian time was not only prolific but also very varied. It was, moreover, a cosmopolitan one, the Coal Measures faunas being everywhere very similar. In Kansas are known nearly 400 kinds of invertebrates; of shelled forms alone there are 234, divided as follows: brachiopods 46, bivalves 111, gastropods 51, and cephalopods 26. The commonest shelled animals were the spiny brachiopods (*Productus*). Nearly all of this cosmopolitan life was, however, blotted out before the close of the Paleozoic. (See Pl., p. 365.)

Brachiopods are the common fossils of Pennsylvanian time in this country but their places were being taken more and more by the bivalves. The same faunal change also went on in northern Europe,

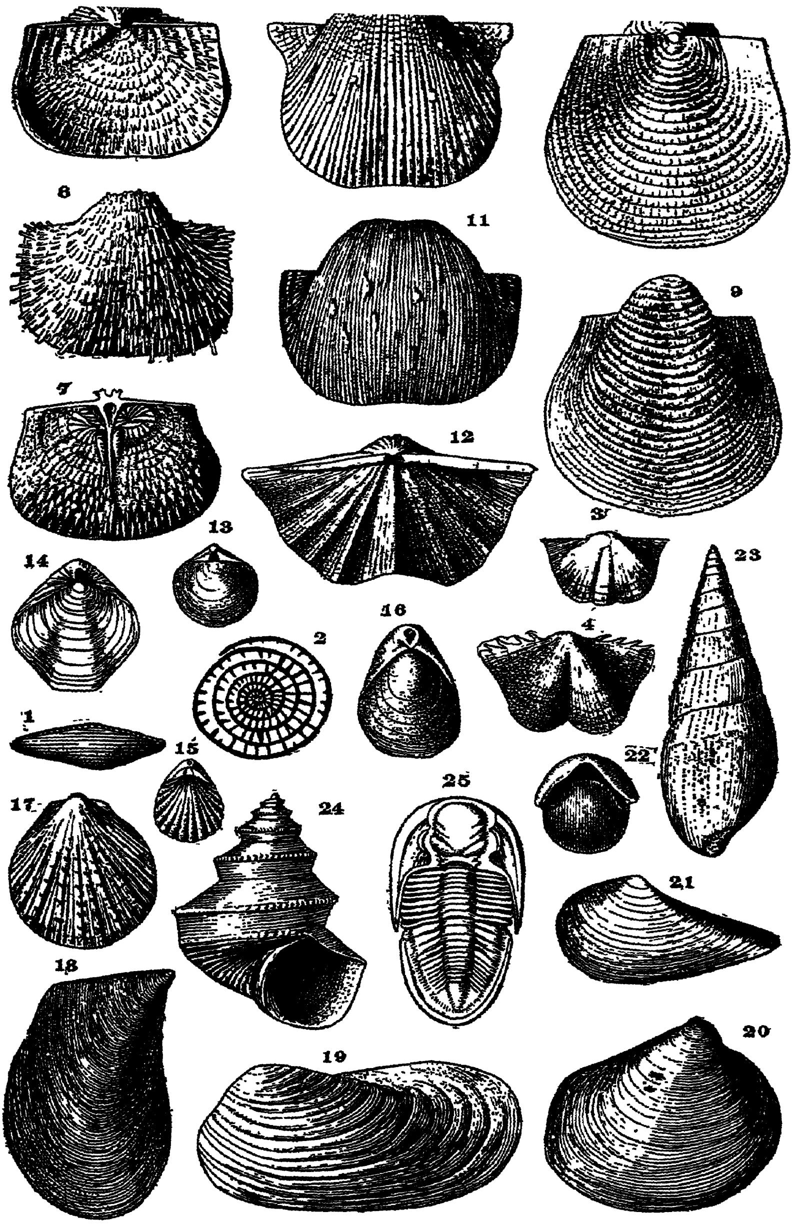

Plate 26. — Pennsylvanian Protozoa (1, 2, Fusulinidæ), brachiopods (3–16, 5–11 productids), bivalves (17–21), and gastropods (22–24), and one of the last trilobites (25).

Fig. 1, *Triticites secalicus*, × 2; 2, same cut through center, × 8; 3, *Chonetes mesolobus;* 4, *C. verneuilianus*, × 2; 5–7, dorsal and ventral valves, and dorsal interior of *Productus nebraskaensis;* 8, 9, *P. punctatus*, × ¾; 10, *P. semireticulatus;* 11, *P. cora*, × ½; 12, *Spirifer cameratus*, × ¾; 13, *Ambocœlia planoconvexa*, × 2; 14, *Composita subtilita*, × ¾; 15, *Hustedia mormoni;* 16, *Dielasma bovidens;* 17, *Pseudomonotis hawni*, × ½; 18, *Myalina subquadrata*, × ½; 19, *Allorisma subquadratum*, × ½; 20, *Schizodus harii;* 21, *Leda bellistriata*, × 3; 22, *Euphemus carbonarius*, × 1½; 23, *Soleniscus fusiformis;* 24, *Worthenia tabulata;* 25, *Phillipsia*

but in the Mediterranean region (called Tethys) extending from Sicily into India, the waters still swarmed with brachiopods into Permian time. While the brachiopods were vanishing, the shelled cephalopods in the goniatid and ammonid stocks were rapidly changing into a variety of forms characteristic of Permian times (see Fig., below).

Fusulinids. — Among the minute and lowly organized animals little has as yet been said about the Protozoa, whose individual organization is contained in a single cell, and which represent the first form of animal life. These Protozoa are tiny, naked or shelled globules of streaming protoplasm, with a central,

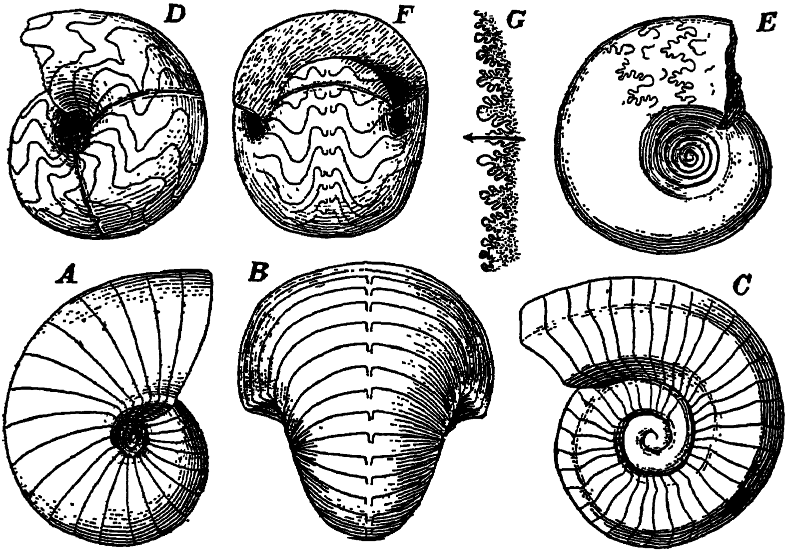

Fig. 125. — Characteristic cephalopods of the Pennsylvanian. Nautilids: *A*, *B*, *Solenocheilus kentuckiense*, × $\frac{1}{2}$; *C*, *Domatoceras militarium*, × $\frac{1}{2}$; Goniatids: *D*, *F*, *Glyphioceras incisum*, × 2; Ammonids: *E*, *G*, *Waagenoceras cumminsi*, × $\frac{1}{3}$. From the Texas State Survey.

more solid sphere known as the nucleus, which is the actual seat of vital energy or life. They sometimes live singly, but more commonly are combined into colonies. They are known as fossils since the Middle Cambrian, but were not rock makers until later Mississippian time. The forms with calcareous shells are known as the *Foraminifera*, a name referring to the numerous perforations in the shell. Of these, in the Pennsylvanian and early Permian the fusulinids (meaning *spindle-form;* the colonies look like grains of wheat) abounded on the bottoms of the seas and were often limestone makers (Pl., p. 365, Figs. 1, 2). They are known almost everywhere in the northern hemisphere where Pennsylvanian deposits occur. Even in far northern Spitzbergen above 76° north latitude their fossils are still abundant. Similar colonial foraminifers live to-day only on the bottoms of warm-water seas and on coral reefs.

The Mountains of Pennsylvanian Time

Paleozoic Alps of Europe. — The late Mississippian and Pennsylvanian periods were times of marked crustal movement, resulting in far-reaching changes in the distribution of land and sea. In central and western Europe, the movements began shortly after the close of Culm time, were renewed in the Upper Carboniferous, and again in the Permian. In the heart of Europe there arose a mighty chain of folded mountains, the *Paleozoic Alps of Europe,* whose stumps of massive rocks may be seen in Germany, France, Belgium, England, and Ireland to-day (see map, p. 352; their general distribution is shown in Fig., p. 387, of Pt. I). The western ranges extending from Ireland across Wales and southern England (the Mendip system) to the central plateau of France, Suess has named the *Armorican Mountains;* the eastern ranges extending from southern France across the Vosges and the Black Forest to the Thuringian Forest, the Harz, the Fichtelgebirge, Bohemia, and the Sudeten, and possibly even farther east, he calls the *Variscian Alps.* Mountains also arose in the Pyrenees, the Spanish Meseta, Corsica, Sardinia, and the Alps. The folding of the Urals likewise began in later Carboniferous time and attained its climax in the Permian. Even in Armenia, central and eastern Asia (Altai, Tianschan, etc.), and South Africa, Australia, and the Andes can be followed the traces of the mountain-making movements of this time (see Fig., p. 368).

D. N. Wadia states that in late Pennsylvanian time there was in the Himalayan region "a great revolution in the physical geography of India," and that this orogeny blotted out for a time the Tethyan sea.

Intrusives. — Hand in hand with these dislocations arose enormous masses of eruptive rocks, especially granite in stocks and bathyliths, accompanied by porphyries of various kinds. The granitic rocks of the Harz, the Thuringian Forest, the Erzgebirge of Saxony, the Vosges and other regions are of Carboniferous age. Outside of Germany the intrusions of granite (mainly laccolithic) and other eruptive rocks played a large rôle in the Carboniferous; for instance, in Brittany, Cornwall, Scotland, and southern Norway.

The Rising Mountains of North America. — Just as high mountains arose in western Europe shortly after the close of the Lower Carboniferous (Culm or Dinantian), so similar ones came into being in America at the end of the Mississippian. In the chapter on the latter period was described the rising of mountains in Alabama, Arkansas, and Oklahoma, and others in eastern Canada. We will now trace the renewed risings of those areas in Pennsylvanian time.

The ancient land *Llanoris of Louisiana and Texas* was in movement, we are told by McCoy, early in the Pennsylvanian (close of Bendian series) and again later in this period (Cherokee time). Toward the close of Middle Pennsylvanian time (Canyon) came into being the Arbuckle Mountains of Oklahoma, and at the close of the period the Wichitas farther west in the same state. These movements are equivalent to the Hercynian ones of Europe.

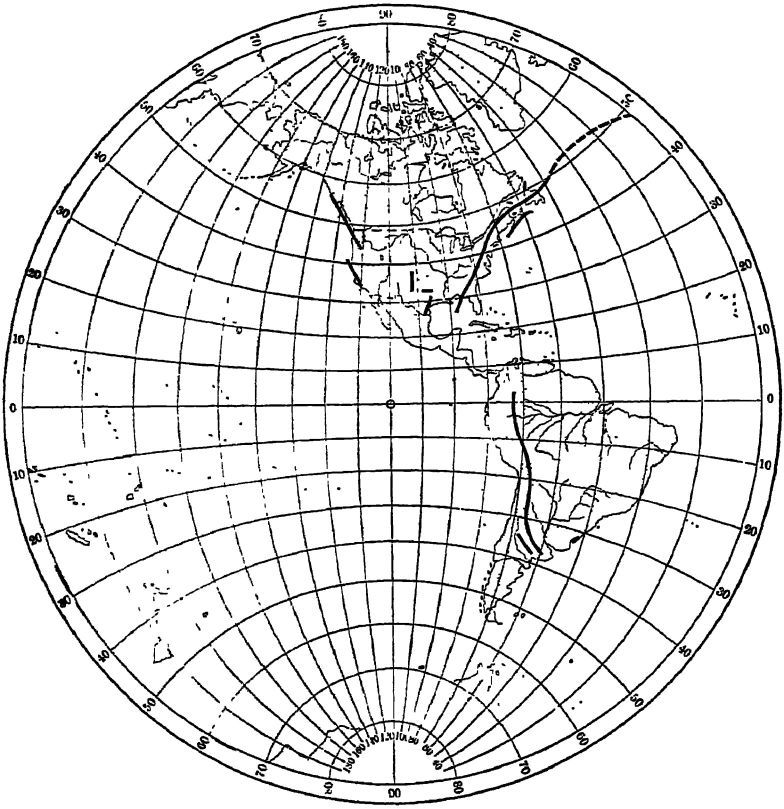

Fig. 126. — Stereographic map of the western hemisphere, showing the position of the Appalachian and other mountain ranges elevated toward the close of the Paleozoic.

The coarse and thick deposits of the late Pennsylvanian and Permian in New Mexico, Colorado, and Wyoming, known as the red beds, have recently been interpreted by Lee as the débris brought down from a newly arisen area to the east of them. These mountains, *the ancestral southern Rockies*, were also the source for most of the red beds of central Texas and Oklahoma, a region that in Pennsylvanian time, however, was getting its sediments from the southeast

or Llanoris. This orogeny completely changed the geography of the area of the southern Rocky Mountains, and different seaways with different faunas lay on either side of these mountains.

Along the *Pacific border* the Pennsylvanian marine formations are interbedded with much extrusive igneous material, testifying to an abundance of volcanoes from northern California north into Alaska, and these seemingly show that mountains were also forming here.

The region of New Brunswick and Nova Scotia of the *Acadian area* is a fine one to illustrate in intermontane marine and continental deposits a successive series of elevations. Here may be studied two movements that made for intermontane seaways, and four that are recorded in fresh-water valley deposits. The first movement, toward the close of the Devonian, let in the sea only partially (Horton-Albert series); then came the second orogeny, bringing in the Windsor sea of late Mississippian time. This period was closed by a third time of mountain making, which blotted out in Acadis nearly all the seaways. In Pennsylvanian time the fourth movement came early in the Westphalian, and the fifth after this epoch. The sixth is of Permian time.

Bell, in his studes of the Acadian region, tells us that in early Mississippian time there was laid down about 3400 feet of coarse fresh-water deposits (Horton-Albert). Then came the first of four movements of Carboniferous time. Limited seaways entered in between the mountains and laid down about 2000 feet of late Mississippian formations (Windsor). In latest Mississippian time there was a second period of mountain making, which appears to have been the strongest of the four. The succeeding continental deposits, of Pennsylvanian age, in their overlapping and transgressive character, all show more or less of an angular unconformity beneath them. The first of these are the conglomerates of southern New Brunswick, followed by the Lower Westphalian coal series of New Glasgow, the Fern Ledges of St. John, and in part the Millstone Grit of the Sydney area and Prince Edward Island, together having a thickness of more than 5000 feet. Next came the third orogenic movement, of Middle Westphalian time, resulting in the conglomerates of the Joggins, Parrsboro, and New Glasgow areas, and the late Westphalian coal series of the Joggins basin, with a total thickness of more than 6800 feet. Finally came the last of the four Carboniferous deformations, of post-Westphalian time. It was followed by the deposition of the youngest conglomerates of the Joggins area and the Lower Stephanian coal series of Sydney, whose thickness is not less than 2100 feet (6000 feet in Prince Edward Island). Finally, in Permian time, there was another deformation, since none of the Carboniferous strata remain in their original attitude of deposition.

Climate

Previously it has been stated that the late Mississippian flora was an impoverished, restricted, and stunted one, while that of Lower Pennsylvanian time was much expanded and differentiated,

leading White to conclude that an "unmistakable climatic amelioration" had taken place.

In this connection it will not be amiss to point out that Taff in 1910 reported the finding in the Caney shales of southeastern Oklahoma (near Talihina) of grooved and striated limestones, and erratics in sizes up to 50 feet across. The markings on these stones Woodworth ascribes to internal rock movements accompanying the faulting of the beds. He agrees with Taff, however, that the distribution of the bowlders, aside from the nature of their striated surfaces, demands transportation by ice. Further, that at the time of the Caney the

Fig. 127. — A reef of tetracorals (*Campophyllum*) and tabulates (*Chætetes*) in the Pennsylvanian (Moscovian) of western Spitzbergen. Photograph by Olaf Holtedahl.

climate was cold enough to permit "floating ice in continental bodies of water and also in the sea in middle latitudes" (1912). To these opinions may be added another by Ulrich, who also concluded that these erratics of the Caney owe their transportation to "heavy shore ice" (1920). This was in earliest Pennsylvanian time when there were high mountains in Llanoris.

From this cooler climate of earliest Pennsylvanian time, those of later epochs became rapidly warmer, equable, and humid. Great swamps at sea-level in many lands of the northern hemisphere were storing vast quantities of coal — carbon taken from the atmosphere

and water — and even greater amounts of carbon dioxide were being laid away in the limestones of the seas and oceans. Proof of a mild climate is found in the luxuriant coal floras, which are devoid of all evidence of a non-growing season, that is, the logs have no growth or annual rings until near the close of the Pennsylvanian; in the profusion and great size of the insects; in the wide distribution of the fusulinids; and in the occurrence of coral reefs in Spitzbergen (Fig., p. 370). With the rise of the European Alps the floras underwent changes, and these changes were more marked in that continent than in America, for the floras and insects of earliest Permian time in the United States still indicate a climate devoid of winters, though the air was drier, the red beds and gypsum deposits pointing rather to a semi-arid climate.

The semi-aridity of early Permian time begins to appear in late Middle Pennsylvanian time (Conemaughan), when the spore-bearing plants were greatly reduced in numbers, and there appear for the first time the pinkish colored strata which indicate " short dry seasons " and a climate still free of frost. The same climate was continued in the Upper Pennsylvanian, and the seed-plants began to expand rapidly, along with the first introduction of cycadaceous forms. Then shortly after earliest Permian time a marked reduction of climate took place, leading to the development in the southern hemisphere of the cool-climate flora to be described in the chapter on that period.

Iron-ores and Fire-clays of the Coal Measures

Iron-ores. — In places where coal beds abound one rarely sees red or yellow rocks. The color is generally gray to light greenish, or even whitish, for the sandstones, while the shales, though they may be greenish to black above the coal beds, are usually more or less white clays beneath them. This lack of strong red and yellow colors, which are produced in rocks by ferric oxide (hematite and limonite), is due to the fact that in the presence of organic matter, either in the coals as they were deposited or in the solutions passing downward from them, the ferric iron is reduced to ferrous and then unites with carbon dioxide to form ferrous carbonate. The latter is not a coloring agent and by this change, the chemical aspect of which has been previously discussed, Pt. I, page 172, the strata are decolorized except as they may be gray to black from included carbonaceous material. As shown on pages 172 and 181 of Pt. I, the ferrous carbonate thus formed, being, like carbonate of lime, soluble in water containing carbon dioxide, may be removed in solution,

leached out and concentrated elsewhere. By passing into shallow bodies of standing water the carbon dioxide might escape, the iron be re-oxidized by the aid of the iron bacteria and precipitate as hydrated ferric oxide (limonite), forming the so-called *bog iron-ore.* But in the presence of abundant organic matter, such as the swamps and marshes of Carboniferous time possessed, this re-oxidation was prevented and the iron concentrated and deposited as the ferrous carbonate. Sometimes the iron-ore was mixed with more or less clay from muddy water and this variety is known as *clay iron-stone;* in other cases it was more or less mingled with black peaty matter, in those swamps where there was prolific vegetation, and this forms the valuable *black-band ore*, which occurs in Ohio and Pennsylvania.

These iron-ores are found in beds of any thickness up to 50 feet, but are usually under 4 feet, and like the coal beds may be repeated many times in a section. They are also often underlain by fire-clays, or the iron-stone concretions occur in the clays.

Fire-clays. — Fire-clays, when impure, are more or less sandy, but are usually aluminous. The aluminous type is the true fire-clay, and is so named because it is capable of resisting heat to a high degree and is much used for making fire bricks to line the insides of blast furnaces. The purest white clays are used for the making of pottery and tiles. The purity of these white clays is due to the presence of carbonic acid in the depositing waters, which takes away the iron and also the particles of feldspar which it decomposes. When some of the feldspar still remains, furnishing soda, potash or lime to act as fluxes, the clays are fusible and are not good fire-clays.

Collateral Reading

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CHAPTER XXVIII

THE RISE OF THE LAND FLORAS

Plants of some kind occur in all lands and under all climates. They are not restricted to the moist soils of the valleys, but live also on the highest mountains and even sparingly in the driest deserts. In the shallow fresh waters are found many kinds of plants, and on the ocean bottoms down to a depth of about 600 feet grow the attached seaweeds. Fastened to rocks, trees, and other objects are the brown and gray lichens, a thin film of spreading plant matter. In the moist forests and on the meadows occur the fungi, including the common toadstools, plants devoid of chlorophyl and feeding on the humic material (vegetable mold) of other dead and dying vegetation. A vast variety of microscopic plants, the bacteria, live everywhere — in the soil, in nearly all waters, in the oceans, on and in other plants and animals. They and the fungi are Nature's main agencies for dissolving dead organisms, consuming oxygen and giving off carbon dioxide. The yeast bacteria convert sugar into alcohol by fermentation, and are used in the making of alcoholic liquors; other bacteria are useful in the making of cheese; still others cause diseases, and are found even in all healthy organisms.

Paleozoic Floras. — From the geologic record we learn that the first known flora came into existence in the latter half of Devonian time, though a few land plants are known from the Silurian. We are probably right, however, in considering that the low-lying lands were clothed with a green verdure from at least the beginning of Champlainian time, but that the early plants had not yet acquired sufficient woody tissue in their organization to be preserved in the sediments, and hence have no significance in Historical Geology. Since Middle Devonian time land plants with woody tissue have become more and more prolific and have grown to greater dimensions and higher stature, all of which means that they also have gradually attained a longer individual growth.

Swamp Life of the Pennsylvanian. — The coal floras of late Paleozoic time are now well known, and it is estimated that upwards of three thousand species have been described (see Figs., pp. 360 and 374). They are conspicuous for their almost world-wide distribution

Fig. 128. — Pennsylvanian swamp flora, as restored by Unger. Note the majestic scale trees (*Lepidodendron*) with tree-ferns and seed-bearing fern-like plants (Pteridosperms) in the middle distance.

and their luxuriance and abundance, along with a dense and varied undergrowth. Their most striking representatives in number and size are the scale trees, a sort of evergreen having comparatively small needle-like leaves; some of these trees grew to over 100 feet in height, and to a diameter ranging up to 6 feet (see Pl., p. 377). There is in them an absence of rings of growth, indicating also an absence of seasons until near the close of Pennsylvanian time. Another remarkable group, the gigantic calamites or rushes (Pl., p. 381), grew to at least 60 feet long and 15 inches thick. They resembled the living cane brakes and bamboo thickets. These floras also included many fern-like forms, both delicate and hardy, some of which were climbing in habit, while others grew into majestic trees (Fig., p. 374); most of them bore seeds, but some were spore-bearing and therefore true ferns.

In general, these forests must have reared their tops higher than 40 feet. They were of rapid growth and of soft and even spongy woods, as seen in the smooth, hard, and persistent bark, in the large and thin-walled cells of the woods, with a comparatively large amount of medullary and cortical tissue and large intercellular spaces, and in the many water-pores in the leaves.

Shades of green were the dominant color, and the monotone of the verdure was nowhere enlivened by bright flowers. Flowers, however, were present, but of a low order, insignificant in size and doubtless unattractive. Probably more than one half of the flora was spore-bearing (heterosporous) and we may safely regard most of the more common plants of the Coal Measures as seedless. Fertilization was not yet accomplished through the aid of honey- and pollen-eating insects as is so general among the living flowering plants of the present, but was brought about in most of the coal floras by the rains and winds. At the time when the spore-producing trees and ferns were liberating their spores, the entire forest was covered with a greenish yellow or brown dust, and some of the coals are largely made up of these spores (White, and Jeffrey).

Spores (Pl., p. 377, Figs. 4–6) differ from seeds in that the latter give rise directly to sexed plants, while the former also develop into sexed ones, but these are short-lived and in turn give rise to the sexless, long-lived plants that bear the spores. In other words, the spore plants have an "alternation of generations," while the seed plants have direct development. This matter will be taken up again later in the chapter.

The air was not scented with sweet odors, for there was no honey, but it is probable that resinous smells such as pervade living conifer forests were present.

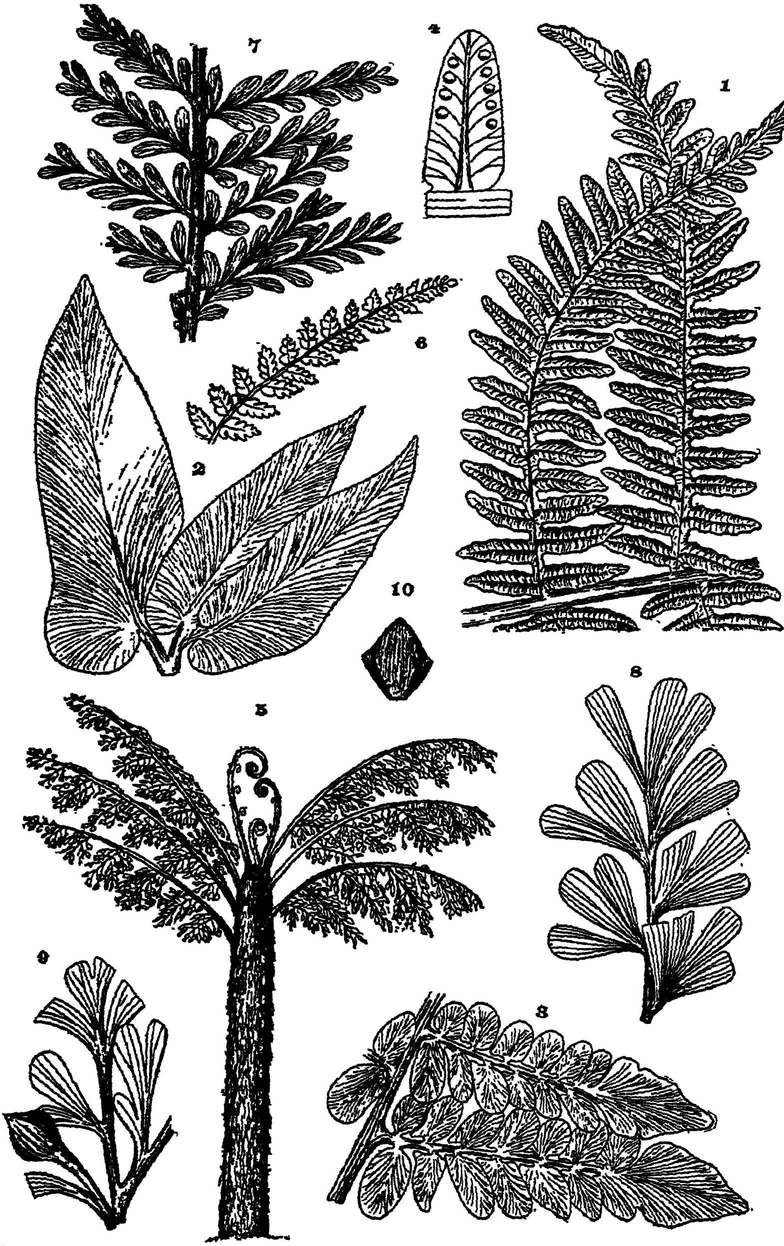

Plate 27. — Ferns (1, 4, true ferns; 2, 3, 5, doubtful ferns), and seed-bearing fern-like plants (Pteridosperms) (6–10).

Fig. 1, *Alethopteris grandifolia;* 2, *Neuropteris fasciculata;* 3, *N. capitata;* 4, *Pseudopecopteris mazonana*, with spore cases; 5, probably a seed-bearing fern-like tree, *Megaphyton*, restored by Kidston; 6, *Sphenopteris mixta;* 7, *Archæopteris stricta;* 8, *Aneimites fertilis*, × 2; 9, same with a young seed, × 4; 10, same, one of the seeds restored, × 3. Figs. 1–4, 6–7 from the Illinois and Ohio State Surveys; Figs. 8–10 after David White.

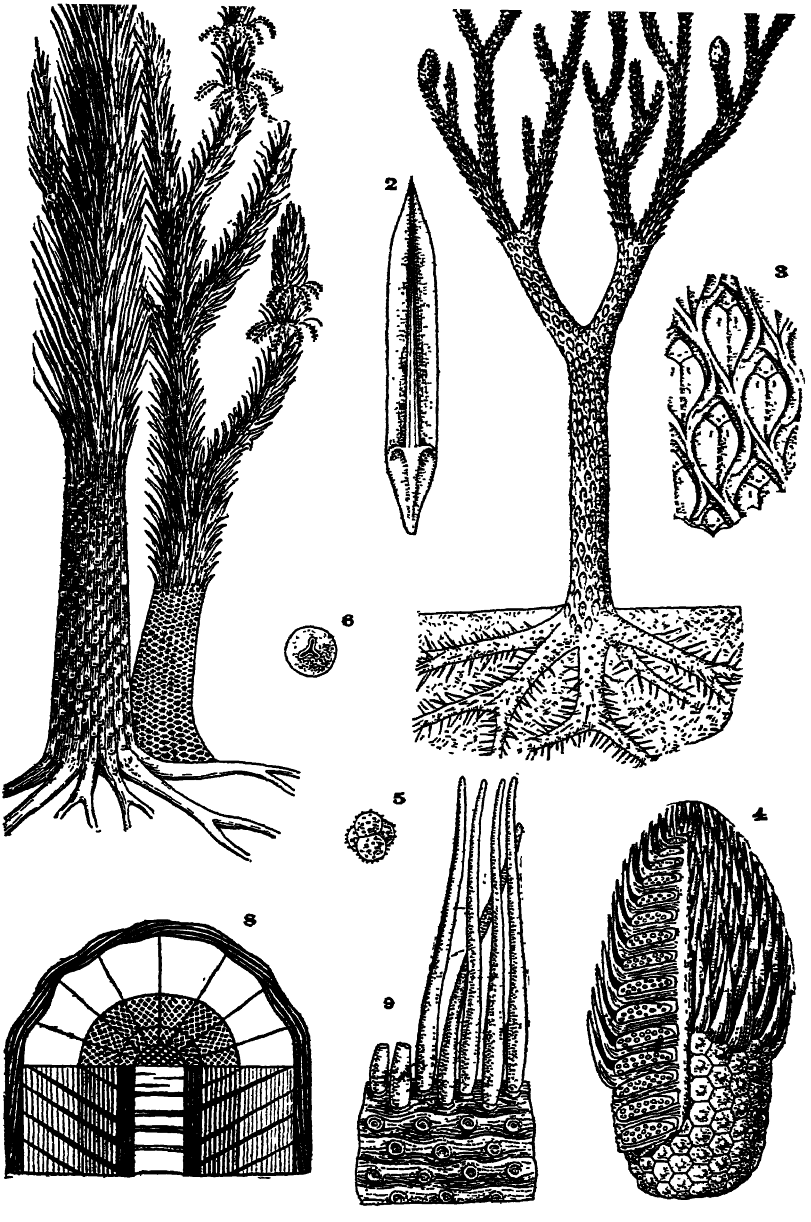

Plate 28. — Scale trees of the Pennsylvanian.

Fig. 1, restoration of the tree *Lepidodendron*, about $\times \frac{1}{100}$; 2, leaf of the spore-bearing cone, about $\times \frac{1}{2}$, those of the branches being very similar but longer; 3, outer surface of tree, showing nature of leaf bases, about $\times \frac{1}{2}$ (*L. obovatum*); 4, spore-bearing cone (*Lepidostrobus*), with and without leaves, sectioned to show spores and spore-developing cases (sporangia); 5, bunch of four microspores; 6, macrospore; 7, two species of the tree *Sigillaria*, restored, about $\times \frac{1}{50}$; 8, section through trunk, showing relative thicknesses of outer leaf-bearing layer, two zones of cork-like bark, comparatively thin internal cylinder of wood, and medial pith; 9, roots of these trees (*Stigmaria ficoides*), with rootlets and scars of their attachment. Figs. 1–6 after Steinmann; Figs. 7 and 8 after Zittel.

In these forests of Pennsylvanian time might have been seen flying about the largest insects that have ever lived, great "dragon-flies," reaching a wing spread of 29 inches. Huge cockroaches abounded everywhere in great variety, giants of 4 inches in length not being rare (see Pl., p. 363, Fig. 4). As a rule, these insects were carnivorous, and did not transfer the pollen from one flower to another, with resulting cross-fertilization, as is so commonly done by living insects among present-day plants. The smaller insects were preyed upon by scorpions and spiders, the latter not making webs but living on the ground or in rotten logs, along with many myriapods, or thousand-legs. No insects of this time, so far as known, produced chirping or other sounds, and the soughing of the wind among the trees was interrupted only by the croak of amphibians in the marshes. Amphibians were common in the swamps, and it is probable that many small reptiles were running over the ground and about the trees. No larger land animals, such as we know, and no birds were to be seen.

Classification. — For our purposes, plants are most conveniently divided into (1) those which have no flowers but reproduce by spores and go through an alternation of generations (*Cryptogams*), as explained above; and (2) those which have flowers and reproduce directly from seeds (*Phanerogams*).

In this chapter we are to study the earliest land plants, and as these can be preserved as fossils only if they have fibrous or woody material, the paleontologist is not directly concerned with the lower Cryptogams.

All of the *higher plants* above the mosses in organization are characterized by having roots, and by the occurrence in their soft tissues of what are known as *vascular bundles*. These bundles are composed of tough, hollow, interlacing fibers, whose primary function is to serve as conducting channels (hence vascular, from *vasculum*, a small vessel) through which the various food materials pass, the water and salts ascending and the sugar and proteids descending; secondarily, they are of importance as forming supporting skeletons of the plants. All of the woody material is composed of these strands, and it is this tough substance which makes it possible for leaves and other parts of plants to impress upon the sediments the traces of their former existence.

The further classification may be expressed as follows:

Lower Cryptogams, spore-bearing plants
- **Thallophytes,** bacteria, fungi, most marine plants (algæ)
- **Bryophytes,** mosses

Higher Cryptogams, also spore-bearing
- **Pteridophytes,** ferns (Pl., p. 376, Figs. 1–5)
- **Arthrophytes,** living rushes and Paleozoic calamites (Pl., p. 381, Figs. 1, 2)
- **Lepidophytes,** scale trees or lycopods (Pl., p 377)

Phanerogams, seed-bearing plants
- **Gymnosperms,** plants with inconspicuous, imperfect flowers
  - **Pteridospermophytes** (or Pteridosperms), fern-like plants (Pl., p. 376, Figs. 6–10)
  - **Cycadophytes,** cycads (Figs., pp. 27 and 386)
  - **Coniferophytes**
    - **Cordaites,** ancient evergreen trees (Pl., p. 381, Figs. 3–6)
    - **Conifers,** modern evergreen trees
    - **Gingkos,** maidenhair trees (Pl., p. 381, Fig. 7)
- **Angiosperms,** true flowering plants

Spore-bearing Flowerless Plants

Ferns or Pteridophytes

Nearly everyone knows what a living fern looks like, but when this knowledge is applied to the Paleozoic plants of similar appearance, even the best of botanists cannot at present be certain in many cases that the form studied is a true fern. In the previous century, it was still believed that fully one half of the Carboniferous plants were true ferns and that these beautiful forms dominated the floras of that time. Due, however, to the accumulation of botanical knowledge, and more particularly to the discovery of specimens bearing the reproductive organs, it is now known that many of the so-called Paleozoic ferns bore seeds and therefore were of a higher organization and must be classified wholly apart from the true ferns. These were the seed-ferns, in many ways transitional between the spore-bearing ferns and the seed-bearing plants (see Pl., p. 376, Figs. 6–10). Probably more than one half of the Paleozoic plants formerly regarded as ferns (about one thousand species) will eventually be shown to be seed-bearing.

Living Ferns. — There are living to-day upward of six thousand different kinds of ferns, ranging from tiny, delicate forms to the beautiful tree-ferns of tropical lands, which grow to a height of 50 feet. The greatest variety occurs in the tropics, but herbaceous ferns are found under all climates, even in icy Greenland. As a rule, however, they prefer wooded humid regions. The fern plant is the sexless generation. Its spores are usually developed on the under side of the leaves in spore-cases, a number of which are always clustered together. In each one there are many microscopic spores which are all alike, and these are often developed in countless numbers (see Pl., p. 376, Fig. 4).

A few of these spores may germinate in the ground, giving rise to a sexed plant, the *prothallium,* which is usually a heart-shaped, primitive, green shoot lying prostrate on the ground and often less

than 0.5 inch in length. On its under side are developed male organs that give rise to male cells or pollen, and female organs that when pollenized develop certain cells into sexless plants. We have here, therefore, an *alternation of generations*, that is, non-sexed plants giving rise to sexed plants, and these in turn producing the non-sexed ferns.

In the smaller herbaceous ferns there is a short, stout, underground stem that gives rise to many leaf stems, each of which develops curled up in a spiral, remaining so for a year or more. Subsequently the stems uncurl and grow rapidly into the fully developed leaves, generally called *fronds*. These may attain a great length, as in the tree-ferns, and are called fronds because the leaves are compounded of many leaflets.

In the tree-ferns there is but a single unbranched stem resembling a palm trunk, and the fronds, consisting of one or more leaves with their many leaflets, are developed at the top as a crown, each frond uncurling as it attains full growth. The trunk bears the scars of the fronds that have dropped off and beneath this outermost layer there is often a thick zone, the bark, which surrounds the more or less large, central, woody cylinder (Pl., p. 376, Fig. 5).

Fossil Ferns. — Ancestral ferns (Marattiales, or ferns developing from a single cell) were rare in the Devonian and are not common as fossils until the Pennsylvanian, where many species of the smaller herbaceous kinds occur associated with the tree-ferns (see Pl., p. 376, Figs. 1, 4). The latter kinds became conspicuous for the first time in the Pennsylvanian and were plentiful in the later half of this period and in the early Permian. The stem in some instances attained a height of 50 feet, and in certain forms the fronds developed in two or four parallel columns, but in most cases they were placed spirally around the trunk (see Pl., p. 376, Fig. 5).

Rushes or Arthrophytes

Among living plants there is a small group of forms having a very wide distribution and popularly known as rushes (similar to Pl., p. 381, Figs. 1, 2). As a rule, they are small, less than 18 inches tall, appearing in wet places early in the year; in Central and South America and Cuba, however, a giant form occurs in groves, attaining a height of 40 feet, but with a stem that does not exceed an inch in diameter. This and all other living forms, about twenty-five in number, belong to the genus *Equisetum* (see also Fig., p. 468).

This living genus of rushes has in the ground a non-sexed, perennial, creeping and branching, horizontal root-stalk, that at inter-

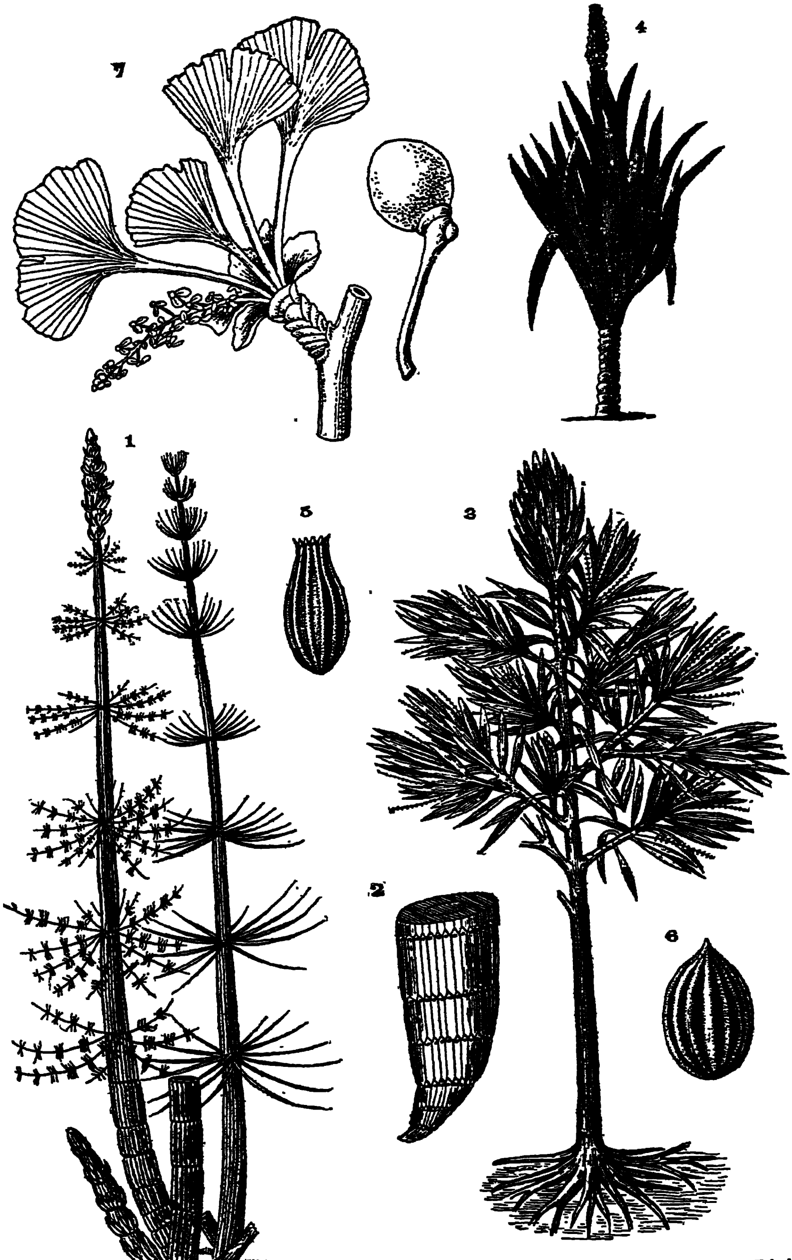

Plate 29. — Calamites (1, 2) and cordaites (3–6) of the Pennsylvanian. Living maidenhair tree or gingko (7).

Fig. 1, calamite trees restored, the one on the left bearing a spore case, about $\times \frac{1}{100}$; 2, basal end of a calamite; 3, cordaite tree restored (*Dorycordaites*), about $\times \frac{1}{100}$, also showing nature of catkin-like flowers; 4, different type of cordaites, about $\times \frac{1}{10}$; 5, *Trigonocarpon ornatum*, a fruit or seed of a cordaite; 6, *Rhabdocarpus apiculatus*, seed of a cordaite; 7, branchlet of the living maidenhair tree (*Gingko biloba*), showing leaves, male flowers, and on the right the mature seed.

vals gives rise to upright aërial stems and descending roots. The stems consist of a thin, externally striated, woody zone, with a large pith center. At regular intervals the stem is divided into *internodia* by transverse partitions called *nodes,* and from these arise the whorls of small or reduced leaves, with one or more longitudinal veins, and also the branches when such are present. The branches repeat on a smaller scale the general features of the stems. At the top of the stem or on the branches occur the spore-bearing cones.

Fossil Calamites. — In Paleozoic time, from the Devonian to the Permian, but more especially in the Pennsylvanian, lived a great variety of ancient rushes, the largest of which are known as the calamites (Pl., p. 381, Figs. 1, 2). They were prolific plants and White says that in America they attained a diameter of up to 12 inches and a length of more than 30 feet. In them the wood cylinder was far thicker than in living rushes, and specimens are known having 2 inches of bark outside of the same thickness of wood. The layers of secondary wood were added externally beneath the bark, a type of growth found in modern trees. The nodes were not equidistant throughout as in the living forms, but in the earliest growth were progressively farther apart, and the stems thickened rapidly. Calamites were also far more abundantly branched than is the case in living rushes, and their leaves were proportionately larger. The top of the trunk consisted of a crowded tuft of closely set circles of leaves, and the cones with reproductive spores occurred more or less abundantly on the smaller leafy twigs or at the top of the main stem. As a rule, the spores were all alike in the Paleozoic Arthrophytes, but in some cases they were differentiated into small and large types (*heterospores,* see Pl., p. 377, Figs. 5, 6).

Scale Trees or Lepidophytes

Living Lycopods. — Lycopods is a group name for the very widely distributed, primitive, herb-like, evergreen plants known as ground pines, club mosses, and running pines, the latter being extensively used in floral decorations. There are about one hundred living species of the genus *Lycopodium,* the name, from the Greek for *wolf's foot,* being given because of the appearance of the roots. In the existing floras the lycopods never grow in dense masses to the exclusion of other plants, and therefore are not conspicuous. Their general appearance suggests the larger mosses or smallest branches of pines, since the leaves are always remarkably small.

Fossil Lepidophytes. — In the Paleozoic from Devonian to Middle Permian time, but more especially during the Pennsylvanian, the

Lepidophytes were the dominant plants, and attained gigantic proportions when compared with the greatly reduced living lycopods, for the former were then at the climax of their evolution (Figs., pp. 360 and 374). These trees in Pennsylvanian times liberated their heterosporous reproductive germs in such tremendous amounts as to be a marked factor in coal making (see Pl., p. 377, Figs. 4–6).

In the late Paleozoic there were two main types of Lepidophytes, known as *Lepidodendron* or scale trees and *Sigillaria* or seal trees, terms which have reference to the scale-like appearance of the leaf-bases on the trunks and branches of these trees. Upward of one hundred species of *Lepidodendron* have been described, ranging from the Devonian to the Permian (Pl., p. 377, Figs. 1–3). The trunk tapered slowly and in some forms grew to a height of over 100 feet and a diameter of 3 feet. These trees in their general appearance differed from all modern ones in that the trunk and many of the branches divided into two forks rather regularly. The more slender branches were terminated, as a rule, by linear or oval spore-bearing cones 1 to 12 inches long (Pl., p. 377, Fig. 4).

The leaves of *Lepidodendron* were needle-like, always comparatively small, but having a width at the bottom of 0.5 inch and a length of 6 to 7 inches (Pl., p. 377, Figs. 1, 2). On their under sides there were two lateral grooves, and in these hollows were situated the minute but numerous breathing organs for the extraction of the carbon dioxide from the atmosphere. The leaves soon dropped off, and are usually found attached only to the young growing twigs. The leaf-bases were diamond-shaped and arranged on the branches and trunks in spirals, thus forming the characteristic markings of the trees. The leaf was attached in the upper part of the rhomb (Pl., p. 377, Fig. 3).

Of *Sigillaria* (Pl., p. 377, Fig. 7), about one hundred species have been described, and they differ from *Lepidodendron* in being rarely branched. Trunks have been found with a diameter, just above the roots, of 6 feet, and one attained a height of nearly 100 feet and was unbranched. At the tip, for about 10 feet, these trees were clothed with erect, rigid, grass-like leaves, which in most cases were like those of *Lepidodendron*, but sometimes were far larger and wider.

The leaf scars in *Sigillaria* were arranged in vertical rows with the scars of adjacent series alternating with one another. In many forms the surface of the trunks was longitudinally ribbed, each of the ribs bearing a single row of leaf scars (see Pl., p. 377, Fig. 7).

Sigillaria are unknown in the Devonian and died out before the close of the Pennsylvanian.

The *structure of the trunk* and branches in the fossil Lepidophytes was peculiar in that the greater thickness beneath the outer layer with the leaf scars was composed of two kinds of cork-like bark surrounding a comparatively thin internal woody cylinder that may have been entirely filled with inward growing wood — the endogenous type of growth — or with more or less of pith (Pl., p. 377, Fig. 8). Secondary wood up to 2 inches thick was added to the outer cork beneath the leaf layer, and as this cork was also tough, the trees had considerable resisting power against the winds and storms of that time but were less stiff than the modern forest trees.

Basally, both *Lepidodendron* and *Sigillaria* terminated in from four to seven trunk roots that are thought to have spread almost horizontally in the ground, and there was no vertical or tap root continuing the trunk as in modern trees. These trunk roots each divided once or twice and tapered to a point, burrowing in every direction through the mass of decaying vegetation in the swamp. On their surface were circular scars arranged in sets of five, and to these were attached round tapering appendages radiating in all directions; these latter attained a length of 15 inches and served for the extraction of food and water from the ground (Pl., p. 377, Fig. 9). Such roots are known as *Stigmaria* (from the Latin *stigma*, a mark), and are very frequently seen in the underclays beneath coal beds.

The *cones* of Lepidophytes, while they looked much like those of modern evergreens or conifers, did not have seeds but were filled with spores (Pl., p. 377, Figs. 1, 4–6). The latter grew in large cases, which contained either minute spores, the microspores or fertilizing male parts (Pl., p. 377, Fig. 5), or large ones, the female macrospores (Pl., p. 377, Fig. 6), often forty times larger than the microspores. These two kinds of spores were developed either in different cones or in different parts of the same cone, and there were many more of the minute spores than of the larger ones.

Seed-bearing Flowering Plants or Phanerogams

The seed-bearing plants, which are exceedingly varied and numerous, fall into two great divisions. The geologically older and more primitive group are known as *Gymnosperms* (or naked seed plants), in which the male and female parts may be in separate flowers or combined into one, but are always inconspicuous and often without bright color. The seeds develop in the open ovaries, which are

said to be naked because the pollen falls directly upon the ovules (eggs), while in the higher or true flowering plants (*Angiosperms*) the ovary is covered by a stigma which receives the pollen.

Seed-bearing Ferns or Pteridosperms

In discussing the ferns on a previous page, it was stated that there were in the Paleozoic many plants having all the appearance of being true ferns but known to have borne seeds instead of spores. In other words, these plants had no alternation of generations to complete the developmental cycle, but were sexed plants, that is, they grew directly from the seed into either males developing pollen or females developing seeds which were fructified and developed into an embryo while attached to the plant. They had the general appearance of ferns and had seeds very much like cycads. The discovery of these Pteridospermophyta, or, in common parlance, Pteridosperms, is one of the outstanding achievements of the paleobotanists of the early part of this century. In the origination of seeds, a great forward step had been taken by the Pteridosperms, and it became the dominant feature in later floras (see Pl., p. 376, Figs. 6–10).

The seeds and pollen were borne on independent sexed plants. The seeds may have been small and occurred at the tips of the leaves or hung down on the under side at the outer ends of the lobate leaves, or, if large, were attached to the thick midrib of the frond; *they never occurred in cones.* The seeds varied in size from 0.25 inch up to at least 2 inches in length, often being long drawn out at the free end, where the entrance to the pollen chamber was located. The embryo or nut was surrounded by a husk that in some forms had a thick, fleshy exterior and a hard, stony, inner layer. Similar seeds also occurred in the cordaites, in the gingkos (Pl., p. 381, Figs. 5–7), and in the cycads.

Some of the seed-ferns had long and slender stems, and climbed about other plants; many were herbaceous, and others (*Psaronius*) were as tall and stout as the tree-ferns. They had their origin in primitive ferns earlier than the Middle Devonian, and their climax of development was in the Pennsylvanian and early Permian, but none are as yet known beyond the Paleozoic.

Cycads or Cycadophytes

In the modern warm-climate floras, the living cycads, of about 110 species, are the remainders of a once more diversified group, never very common in the Paleozoic floras, but dominant in those of the earlier half of the Mesozoic era. A striking living example

is the "sago palm" of Ceylon, the source of our edible sago. The significance of these ancient seed-bearing plants in relation to the other flowering plants we have learned largely from the studies of G. R. Wieland; they appear to have arisen out of the Pteridosperms, possibly as early as the Devonian. Cycadaceous plants appeared with the Middle Pennsylvanian but were not common until Triassic times.

The salient feature of cycads is that their short columnar woody stems, having very large pith centers, are encased in a thick armor of persistent leaf bases, with an intermediate felt-like mass. The

Fig. 129. — Living cycads in the New York Botanical Garden in 1908. Plants of this kind were common in Triassic and Jurassic times.

trunks vary in size from very small ones to those of 60 feet in length in living *Cycas*. Cycads grow slowly and do not become mature for many years, and a trunk 6 feet long may be 1000 years old. They are at times wonderfully preserved in Mesozoic strata. The leaves are of various kinds but commonly of the pinnate palm-leaf type, and are much used in floral decoration (see Figs., p. 27 and above).

Conifers or Coniferophytes

Cordaites, or Large-leaved Conifers. — In the Paleozoic, beginning at least with the Upper Devonian, occur logs whose structure is

not very unlike that of modern pines or conifers. In the Pennsylvanian, casts of such logs are often seen in the sandstones, and in the roof shales of the coals the long strap-like leaves of these trees abound; in fact, they often form a good part of the coal. These plants, which are known as cordaites (after the paleobotanist Corda), included a variety of forms, and were the dominant Gymnosperms of Paleozoic time. They were softwood evergreen trees, tall and slender, sometimes 120 feet tall and 3 feet thick. In such tall trees fully two thirds of the trunk was without branches, the upper third or fourth of the stem having a dense crown of them and abounding in simple leaves of large size (see Pl., p. 381, Figs. 3–6).

The leaves in the cordaites were always large, and some are known with a length of 6 feet and a width of 6 inches. Some were strap-shaped, with the free ends either pointed or blunt; others were grass-like, with a length of 20 inches and a width of 0.5 inch. The leaf substance was thick and had parallel veins as in the living yucca (see Pl., p. 381, Figs. 3, 4).

While the woody trunk of the cordaites was very much like that of modern pines, it is distinguished from the latter by always having a central pith which may be of any diameter up to 5 inches. The new wood was formed beneath the thick bark, in other words, was added externally to the previous layers (exogenous growth).

The cordaites were related to the conifers, but, as is seen from the above description, the two groups were very different in their composition. The former were much branched only at the top, did not have cones with seeds but developed them in catkins, the leaves were not needle-like but strap-like, and finally the trunks had a pith center. The cordaites were most closely related to the gingkos.

The gingkos differ from the cordaites at once in the much smaller and lobate leaves, while the trunks are branched throughout nearly their whole length (see Pl., p. 381, Fig. 7).

Conifers or Evergreen Trees. — The evergreen trees, or true conifers of living floras, whose seeds are developed in prominent female cones and the pollen in male cones, are not known to be older in origin than the Permian, but are now the commonest of Gymnosperms. The order embraces the araucarias, the sequoias or California "big trees" (closely related but smaller trees can be traced back to the Permian), the pine, spruce, fir, juniper, larch, cypress, and yew.

Angiosperms or True Flowering Plants

As the true flowering plants do not appear in Historical Geology until the Cretaceous, their description is deferred to the chapter on that time.

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CHAPTER XXIX

COAL AND ITS OCCURRENCE IN NATURE

Carboniferous Time. — The most conspicuous feature of the rocks of Carboniferous time is the many beds of valuable coal which they contain. In North America nearly all the coal of this time was laid down during the Pennsylvanian period in the eastern United States and the Acadian provinces. In other words, the Pennsylvanian coals of North America occur east of the 100th meridian, while most of the younger coals lie to the west of it (see Fig., p. 402).

The more valuable coals of Europe and China were also deposited during the Carboniferous, though in Europe the accumulating began earlier and lasted longer. *By far the greatest amount of good coal in the world was laid down during the time of the Coal Measures;* it has been estimated that seven tenths of it was formed in these, the closing periods of the Paleozoic era.

Nature and Varieties of Coal

Nature of Coal. — Coal is a compact mass of plants more or less altered through decay, the end result of which is mainly carbon. The plants accumulate in swamps as peat, and how peat is formed is explained on pages 175–179 of the first part of this book; now we must consider how the plant material comes to be changed into coal.

Ordinary coal is a compact, stratified mass of plants which have in part suffered decay to varying degrees of completeness. Coal, however, is often also mixed with more or less of local and foreign impurities, usually muds. The plants of a coal may all have been of one kind, but usually are of several or many kinds; when subjected in thin slices to the microscope, however, the recognizable parts are seen to be most often the chemically tough coverings of spores. Some coals appear to be structureless, a sort of solidified jelly breaking readily into cubical blocks, while others are indistinctly fibrous. Along the bedding planes may often be seen fragmentary plants. When heated, bituminous coals soften or even fuse; but it is a mistake to think there is bitumen present,

since these coals consist largely of carbon, with some oxygen and hydrogen. They are therefore better spoken of as *humic coals*, since all coals consist of vegetable matter. When the plant materials decompose in the presence of water, and more or less excluded from the chemical changes of air, there is liberated some carbon dioxide gas; in other words, there is a continuous loss of some carbon and of more oxygen. The process of change is one of carbonization through biochemical decomposition (mainly bacterial) of the greater part of the plants while still in the bog. This decomposition, if continued for a long time, finally changes the vegetable matter into humic coal through the loss of carburetted hydrogen or illuminating gas. During the geological ages occur the succeeding dynamo-chemical changes through the further loss of hydrocarbons, due in the main to pressure exerted by the superincumbent strata (load), or that produced by their folding during the time of mountain-making. The gases then escape either through the pores or the cracks (joints and cleavage) in the strata, but the success of this escape is again dependent upon the presence of overlying shale beds and their internal construction (grain). In general, the shale beds are impervious to the gases and the circulating ground waters, but when sandy or cleaved through deformation, the chances of escape are greatly enhanced, resulting in anthracite coals that are 95 per cent fixed carbon.

Carbonization of Coals during the Geological Ages. — Anthracite differs from humic coal in having more fixed carbon and less of the volatile hydrocarbons. It is well known that volatile matter is constantly escaping from coal, and that the gases thus released may become ignited, causing explosions in the mines. If the volatile matters had been constantly escaping during geologic time, due to the dynamo-chemical changes, we should expect all of the oldest coals to be anthracitic, which, however, is far from being true. On the other hand, *anthracite* is almost invariably *found in strata that are more or less folded*, as in the anthracite field of eastern Pennsylvania (see Fig., p. 391), and when the strata are much deformed the coals are graphitic, as in Rhode Island. Other anthracite fields also in the areas of mountains are those of northwestern Colorado, southwestern Utah, the Cascade Mountains of Washington, and the Cerrillos field of New Mexico. Because of these occurrences it has long been assumed that the mountain-making forces have in some way brought about the change.

Coal beds are nearly always covered by a shale zone, and in coal fields there are always many coal beds and many more zones of

shale than coal. These shale beds prevent the volatile matter of coals from escaping. In the Ohio-Pennsylvania-West Virginia area there are, however, ten horizons of valuable oil in the sandstones, showing that the volatile matter does to a certain extent migrate.

In mountain-making processes it is well known that shales and limestones stretch far more than sandstones and dolomites, and that they do not pull apart so readily, forming rents. However, when the deformation is marked, all of the rocks are much cleaved, as is well shown in the roofing slates of mountainous regions. It is in these areas that the anthracite coals are found (see Fig., below). What more natural inference than that the anthracitic and graphitic coals have lost their volatile hydrocarbons, not so much through the

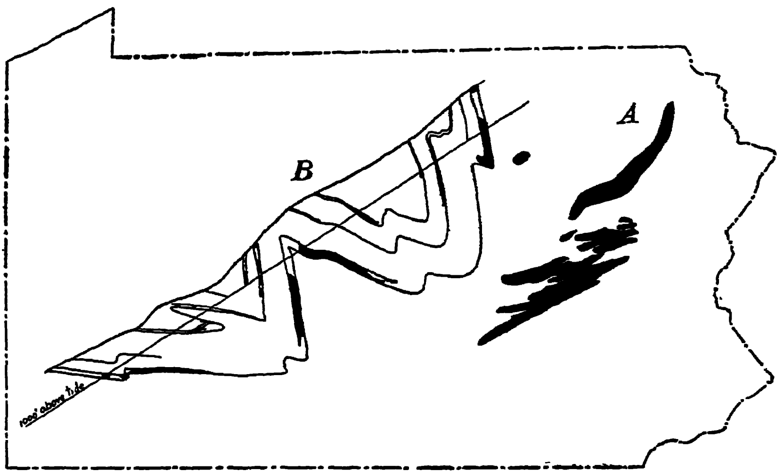

Fig. 130. — *A*, anthracite coal areas in Pennsylvania. *B*, vertical section across the Panther Creek basin in the anthracite region, showing folded nature of the coal beds. U. S. Geol. Surv.

pressure engendered during the time of mountain making as by the cleavage and shattering of the strata, thus permitting the oil and gas, in the course of time, to escape?

Proofs of the Derivation of Coal from Plants. — We shall see that coals, as a rule, lie upon clays filled with roots, and even upon the floors of the former forests. In the roofing shales of coals are to be seen well-preserved fern fronds and the woody stems of many kinds of plants. Many of these stems are covered with a film of coal like that of the coal beds. In the coal itself it is common to see thin zones of impure coal, the worthless *bony coal* of miners (see Fig., p. 392); this is more or less mixed with clay, the result of coal formation where the marshes were invaded by water currents bringing in

mud, and such zones always show plant remains and often very good ones. In fact, in almost any coal, even the anthracites, when allowed to weather, we may see plant fibers.

Good specimens of *Lepidodendron, Sigillaria,* and *Calamites* may be had along some of the bedding planes of the coal. They occur also in the textureless cannel coal (described on p. 393), as in Breckenridge County, Kentucky, where the coal is marked through its whole mass by stems and leaves of *Stigmaria* and *Lepidodendron,* rendered distinct by infiltration of sulphid of iron. Even when nothing of an organic nature is discernible to the unassisted eye, the plant composition of the coals can be made out if suitably prepared thin sections are studied under the microscope. Finally, even the ashes will show vegetable cells.

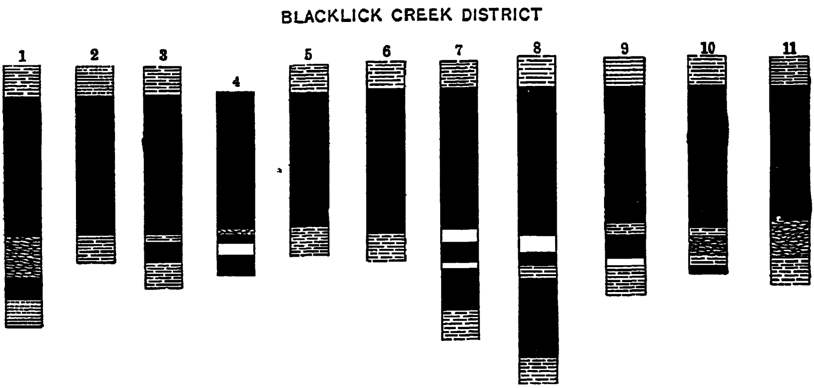

Fig. 131. — Sections through the lower Kittanning coal at eleven different mines in the Blacklick district, Penn. Scale: 1 inch = 5 feet. Solid black represents coal; broken lines, shale; dots, sand; white on black, shaly or poor coal. After W. C. Phalen and L. Martin, U. S. Geol. Surv.

LeConte has truly said that "a perfect gradation may be traced from wood or peat, on the one hand, through brown coal, lignite, bituminous coal, to the most structureless anthracite and graphite, on the other, showing that these are all different terms of the same series. In chemical composition, too, the same unbroken series may be traced. Lastly, the best and most structureless peat, by hydraulic pressure, may be made into a substance having many of the qualities and uses of coal."

Animal Material in Coals. — Fishes, amphibia, and certain kinds of invertebrate animals are at times found in some abundance in certain coals (Linton, Ohio, Fig., p. 360), and there can be no doubt that their decomposed remains have yielded considerable carbonaceous material to the peaty or more volatile varieties.

Varieties of Coal. — The varieties of coal depend upon the purity, the degree of carbonization, and the proportion of fixed and volatile matter. As has been seen, coal consists both of plant or combustible and inorganic or incombustible matter. The relative proportion of the latter varies considerably; good coals have from 1 to 5 per cent ash, while the so called bony coal has from 30 to 40 per cent and is thrown away at the mines. When the ash content is very low, it is wholly the mineral matter taken up by the plants from the ground along with the water; but when there is more than 5 to 10 per cent, it is probably all muds of the bog waters deposited with the plants.

Anthracite is the most carbonized, hardest, and most ideal coal for domestic purposes, since it has the greatest amount of fixed carbon, 90 to 95 per cent. It is a brilliant variety, with conchoidal fracture and high specific gravity, but of low heating power. It has lost nearly all of its volatile materials, and such coals are always found in areas of regionally disturbed and more or less metamorphosed strata. When the coal consists wholly of fixed carbon, it is called *graphite.* This is not usually considered a variety of coal, because it is not readily combustible, but it is evidently the last term of the coal series.

Semi-anthracite is also a hard coal, which has from 80 to 85 per cent of fixed carbon and from 15 to 20 per cent of volatile matter. It is less metamorphosed through regional deformation than anthracite. These coals look much like the former, but are more iridescent in color, burn freely, and do not cake and clog. Their heating quality is high. They are also often known as steam coals.

Humic coals (from humus or vegetable mold) are perhaps the commonest kind, and may be regarded as typical coal. They break rectangularly and hence are often called block coals. They are usually known as soft or bituminous coals, but the latter term is misleading, since coals are not formed of bitumen but of humic materials. In these coals the volatile matter is from 30 to 50 per cent, and hence they fuse and cake when burning; they are therefore used in the making of coke. When the volatile matter approaches or exceeds 50 per cent, the coal is said to be "fat" and is much used in the making of illuminating gas and coke. *Cannel coal* (a corruption from "candle coal," so called because it burns readily with a candle-like flame) is one of the fattiest of coals, and generally rich in hydrogen. It is a dense, dry, structureless, lustreless, black type, breaking with a conchoidal fracture. When the supply of petroleum and natural gas gives out, these coals will be much used in the making of substitutes for them. The cannel coals owe their fatty nature to the kind of plant material of which they are composed, mainly spores that have been converted into jelly-like masses by the bacteria of the bogs.

Lignites are the brown coals that have a woody or clay-like appearance, and when green have water up to 40 per cent. Their heating value is low. Upon drying in the air, lignites slack readily and break up into flat pieces parallel with the bedding. They are in the main of Mesozoic or Cenozoic age.

Sulphur in Coal. — Sulphur increases the liability of coal to spontaneous combustion, and more than 1.5 per cent spoils the coal for the manufacture of gas or blast furnace coke.

The amount of sulphur in coals of Pennsylvanian age is very variable, from a trace to nearly 9 per cent. The average amount in ten anthracite coals from eastern Pennsylvania is 0.6 per cent (0.4–1.0); in seventy-seven humic coals from the western part of the same state it is 1.4 per cent (0.4–5.8); in twenty-four soft coals from Ohio it is 2.2 per cent (0.4–6.3); and in the Indiana-Illinois coals, nineteen samples averaged a little over 2.0 per cent (0.3–4). The anthracite coals of Pennsylvania and the humic ones of the Joggins field appear to be wholly of fresh-water origin, and they have the smallest amount of sulphur. All the other coals are interbedded with strata having more or less of marine faunas, and as these coals are of marshes that were often somewhat under the sea-water, where the sulphur-making bacteria were most abundant, the sulphur content is accordingly far greater. Hydrogen sulphide is found in great abundance in peat beds to which sea-water has access, according to C. A. Davis, and is seldom found in peat formed under fresh water.

Rate of Coal Accumulation. — In the North Temperate region the present peats accumulate in swamps at the rate of about one foot in 10 years. This one foot of plant material, however, after it is covered with 15 to 20 feet more of accumulation, is decomposed, mainly by fungal and bacterial agencies, to about one inch of peat. It appears, therefore, that the present rate of accumulation when measured at a depth of about 18 feet is about one foot of peat per century. On the other hand, it has been noted that plant stems in coal are now from one seventeenth to one twenty-fourth of their original thickness, and this gives some idea how much material is lost in passing from green plants to coal. During Pennsylvanian times, when plants grew luxuriantly, David White thinks the accumulation may have been at the rate of 2 feet per century. Ashley has estimated that if compressed peat accumulates at the rate of one foot per century and the same thickness of coal in three centuries, then it has taken 2100 years to form 7 feet of good coal like that of the Pittsburgh bed. This estimate is probably extreme, because this coal accumulated under a subtropical climate with luxuriant growth. Even so, the biochemical changes are followed by the dynamo-chemical ones resulting from pressure of the superimposed load and from crustal movements, which still further consolidate, devolatilize, and dehydrate the fuel.

As a rule, black coals take much longer to accumulate than do brown coals. This is because in the black coals that result from the more mature kinds of peats, the swamp waters underwent a far better oxygenation, which brought about, through the more decided biochemical changes, a greater destruction of the plant material than in the brown coals where the waters were more stagnant and aseptic.

Thiessen states that coal is chiefly a plant residue, consisting in the main of the most resistant parts, such as the cuticles, spore and pollen coverings, bark, cork, and waxy coverings. These are composed in the main of resins, resin waxes, waxes, and the higher fats, along with more or less of cellulose.

How Coal Occurs in Nature

As a rule, coal beds occur between coarse sediments, that is, are interbedded with sandstones and shales, and there is in the sections a more or less complete absence of marine strata and animals.

Fig. 132. — Coal bed about 2 feet thick, directly overlain by marine limestone (Ames). Corner Woodlawn Avenue and Beaver Street, Allegheny, Pennsylvania.

Limestones may be completely absent, and when they are interbedded with the coaly shales are thin and devoid of undoubted marine organisms. Coal beds are known to lie directly on marine limestones (crinidal in Ohio and Pennsylvania), but still there are no marine fossils even in the very basal layers of such coals. In other words, there is no transition from a pure marine fauna directly into a coal bed. Impure limestones are, however, not uncommonly seen to overlie the coal directly (Ames limestone on 2 feet of pure coal in Allegheny, Pennsylvania, Fig., above), but the contacts are sharp and there is no transition from the coal. The roofing shales of the coals

generally abound in fine fern fronds, but occasionally there are very impure coaly covers that contain phosphatic-shelled brachiopods, or even sparse dwarfed marine faunas (Seville, Illinois). In all such cases these are the basal beds of the invading sea, whose water may or may not have churned up the soft peaty material and then redeposited it as a bituminous mud, along with the enclosed shells.

In the great majority of cases coals are underlain by an underclay that is usually unstratified and filled with the roots and rootlets of plants; in other cases the roots are completely absent though such clays usually have a vertical fracture with some short and slender upright pipes still preserved, which are the casts of once existing roots. These underclays sometimes have the rooted trunks of the former forest still *in situ*, as in the Parkfield colliery, England (see Fig., opposite). Underclays therefore are either old soils or the clayey bottoms of the marshes. These soils may be sandy, but are more often true aluminous clays and are then called *fireclays*. They are described in the chapter on Pennsylvanian time.

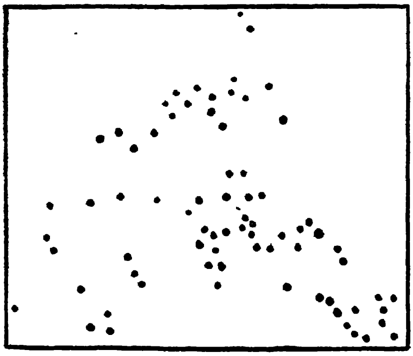

Fig. 133. — A quarter acre of underclay in the Parkfield colliery, England, in 1844, showing in diagram seventy-three stumps in their position of growth. Some of the stumps are 4 to 5 feet across. From Judd's *Lyell*.

Favorable Conditions of Coal Formation. — The most notable physical features of Pennsylvanian time were the many and vast swamps, the great majority of which lay near sea-level. This sea-level was, however, inconstant, and although its fluctuations may not have been greater than 50 feet, yet because of the vast extent of the tidal and delta flats, these latter were widely flooded by the rising of the sea. This oscillation of the sea-level was due to the marked crustal unrest of Pennsylvanian time; with every rising of sea-level, the rivers were dammed back, and the waters over the flats became more or less marine, depositing muds and muddy limestones that often abound in remains of sea life (see Pl., p. 365). During the upwarps of the land, causing the intervals of ebb, the streams were rejuvenated, scouring away some of the deposits on the previous sea floor and spreading over the low lands the thick sandstones and sandy shales, which very rarely have marine organisms (see Figs., pp. 392 and 398). At these times, and also when the sea basins had

been filled with sediment, large salt- and fresh-water marshes and shallow lakes formed, around whose borders became established the marsh floras (see Fig., below), which in time possessed the entire flats and lake areas and filled the basins with peat or jelly-like masses of carbonaceous material. These alternations between the land and the sea were repeated many times.

The conclusion is therefore attained that coal beds, as a rule, are formed naturally in the place of their occurrence, in fresh-water marshes. The coals are chiefly due to growth *in situ* in river deltas and valleys, as are those of the Joggins, or rarely they may be of drifted material in lakes, like those of Commentry. These are the *limnetic coals* (from the Greek word meaning *living in a fresh-water marsh*). Coals were also formed *in situ* near sea-level on the borders of the epeiric seas or on continental shelves by plants that grew behind marine barriers in marshes whose waters were at first brackish but eventually became fresh. These are the *paralic coals* (meaning *growing by the sea*), often of wide areal extent; they embrace essentially those of Pennsylvanian time. The great purity of many coals is further evidence of their having formed where found, for if made of drifted plants, the water currents bringing the latter must of necessity have also carried muds or even sands, which would have been deposited with the organic matter.

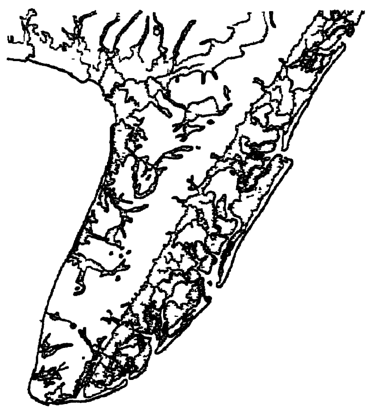

Fig. 134. — Map of Cape May Peninsula, New Jersey. Dotted areas show coastal marshes, to illustrate recurrence of coal swamps in Pennsylvanian time. U. S. Geol. Surv.

Number of Coal Beds in a Coal Field. — In Pennsylvania there are twenty-nine coal beds with a maximum total thickness of 106 feet. In Indiana, there are twenty-five, having an aggregate thickness of 90 feet, and in Illinois there are seventeen. The Coal Measures of South Wales, Bristol, and Somersetshire have eighty-five different coal beds. In the Saarbrücken region of Germany there are as many as one hundred and twenty, not including those less than one foot thick.

Pittsburgh Coal Bed. — The greatest coal swamp of Pennsylvanian time was that which made the Pittsburgh coal bed, extending interruptedly for 225 miles in a northeast-southwest direction and 100 miles from east to west. This

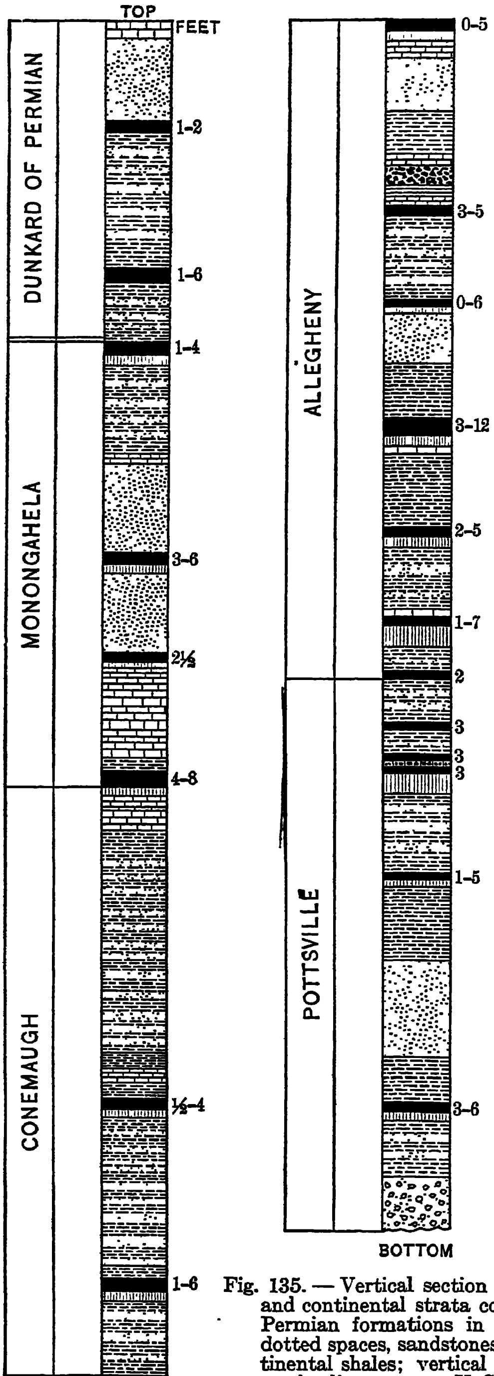

Fig. 135. — Vertical section showing character of the marine and continental strata composing the Pennsylvanian and Permian formations in Ohio. Solid black, coal beds; dotted spaces, sandstones; broken lines, marine and continental shales; vertical lines, fire-clays; block structure, marine limestone. U. S. Geol. Surv.

swamp was twenty-two times greater than the present Dismal Swamp of Virginia-North Carolina; it must not be assumed, however, that all parts of the area were a continuous coal swamp, as there were undoubtedly many intermediate dry places. I. C. White states that the Pittsburgh coal is known to be workable over 6000 square miles of western Pennsylvania, eastern Ohio, and West Virginia, an area six times larger than the Dismal Swamp. The latter, before it began to be drained, covered an area 40 by 25 miles, and is now a great coal field in the making, covered with a layer of peat as much as 15 feet thick in places (see Figs., pp. 177, 178, 181 of Pt. I).

Thickness of Coal Beds. — Coal beds vary in thickness from a mere film up to more than 80 feet. A workable bed must be at least 2 feet thick, and it is very seldom that they are thicker than 8 to 10 feet. The mammoth anthracite bed of Pennsylvania has a thickness of about 45 feet. The Pittsburgh bed of soft coal varies up to 16 feet, with an average of 6 to 10 feet. In the Commentry basin of central France, there is a

single coal bed of Lower Permian age that is locally over 80 feet thick.

Variability in Sedimentation. — In the coal fields there is a marked variability in the sedimentation, sandstones and shales varying the most and being very inconstant in geographic distribution. The more persistent horizons are the thicker coal beds, the calcareous marine shales, and especially the marine limestones. In Pennsylvania there are at least one hundred and fifteen of these alter-

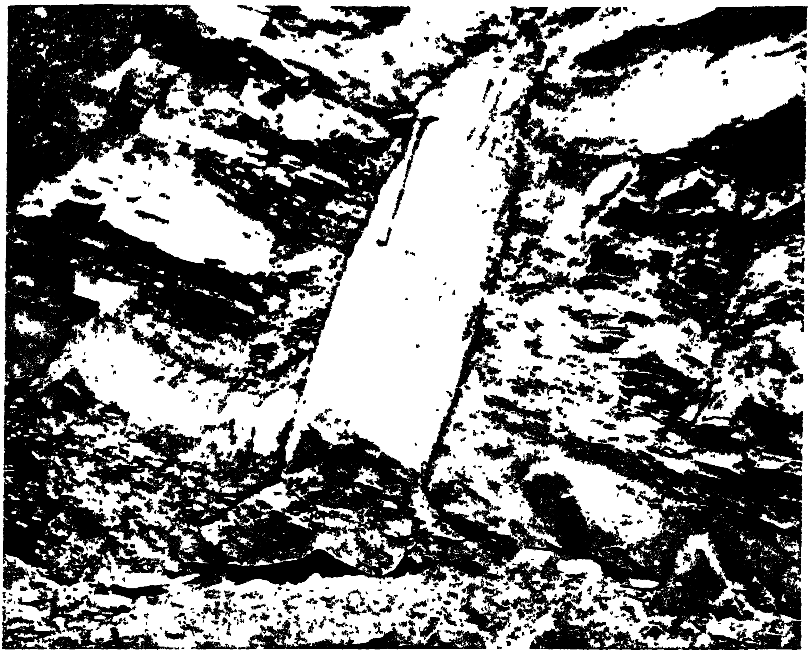

Fig. 136. — A vertical *Sigillaria*, 8 feet long and 18 inches wide, rooted in an old soil, Joggins, Nova Scotia.

nations in 2600 feet of strata, in Indiana one hundred and twenty-one in 1300 feet.

The Joggins Section. — The Coal Measures previously described were deposits more or less under the influence of the sea. We will now turn to the celebrated Joggins section in Nova Scotia, which is of a different origin, and nearly every foot of which can be studied at the head of the Bay of Fundy.

The name Joggins seems to have had its origin in the "jog-in and jog-out" of the shore. The total thickness of the section here is nearly 13,000 feet, and it appears to be all of Pennsyl-

vanian age. Throughout this mass of coarse material, very largely tinged with red, no one has yet found an assemblage of genuine marine fossils, or even a single brachiopod or other undoubted sea animal. The fossils are in the main land plants, but these are abundant only in the roofs of the coals, while the drifted and prostrate logs are nearly all restricted to the gray and green sandstones, where they occur as casts. Logan's "Division 4," with a thickness of 2539 feet, is the main fossiliferous horizon with coal

Fig. 137. — Another *Sigillaria* standing erect in the position of growth, Joggins, Nova Scotia.

formation, and often abounds in fresh-water bivalves, air-breathing snails, bivalve crustaceans, tiny worm tubes, and bones and tracks of Amphibia; even rain-drop impressions are preserved. The coal swamps were, as a rule, of short duration and the more persistent ones were often invaded by muddy water which deposited above the underlying pure coals the many black shaly zones.

A further study of the detail of this section shows clearly that it was only the prostrate logs that were rafted away from their place of growth and whose remains are now seen as casts in the sandstones. The coals themselves, of whatever thickness, were made in fresh-water

marshes in the places where they now occur, since most of them are underlain by the swamp soils still filled with fossilized roots. Not only this, but there are preserved many additional soils whose exposed vegetation was swept away by the waters that brought the invading and covering muds and sands. Still further proof of the origin of the coals *in situ*, that is, where they now occur, is found in the logs of *Sigillaria* and *Calamites still standing erect in the places of their growth* (Figs., pp. 399 and 400). There are many of these logs in superposed tiers, Logan reporting seventy-one such exposed in Division 4 alone (see also p. 396). These standing logs have been admired by all geologists since Richard Brown discovered them in 1829, and the drawings of them by Logan, Lyell, and Dawson have been repeated in most text-books on Geology. They are of all lengths up to 25 feet, and some of them reach 4 feet in diameter. From their evidence we may agree with Lyell that what he saw in 1842 at the Joggins proved the growth-*in-situ* origin of these coal beds. Similar erect fossil trees are also known in England and France.

Pennsylvanian Coal Fields of America.—The coal fields of Pennsylvanian time in America occupy an area estimated at over 252,000 square miles, a total considerably greater than that on any other continent in the world (see map, p. 402). China has the next largest area, in amount somewhat less than that in the United States. Russia has 27,000 square miles; New South Wales, Australia, 16,500; Great Britain, 9000; Germany, 3600; and France, 1800.

There are six coal fields of Pennsylvanian age in North America. These are as follows (see Map 2, p. 355):

1. **Acadian Field.** — The Pennsylvanian coal formations of eastern Canada, estimated at about 18,000 square miles, are in Nova Scotia, New Brunswick, Cape Breton, and to a very limited extent in western Newfoundland. The coals are all limnetic.

2. **Rhode Island Field.** — This is the smallest coal basin, covering 500 square miles in Rhode Island and Massachusetts. The coals are of limnetic origin and are now highly anthracitic and graphitic.

3. **Appalachian Field.** — In eastern Pennsylvania there is an isolated field of limnetic anthracite coals covering an area of but 500 square miles; it is, however, by far the most productive anthracite field in America.

This field also has the most productive area of paralic humic coals in America, covering approximately 70,800 square miles in nine states, extending from the northern border of Pennsylvania and eastern Ohio southwestward 850 miles to central Alabama, and from Appalachis westward to the Cincinnati uplift.

4. **Michigan Field.** — The paralic humic coal field of southern Michigan covers an area of about 11,000 square miles. All prospecting is done with the drill, because the region is deeply covered by glacial material.

5. **Eastern Interior Field.** — This is an isolated coal basin in Indiana, Illinois, and western Kentucky, covering about 58,000 square miles. The coals are soft humic and are interbedded with marine zones.

6. **Western Interior Field.** — This is the largest coal area, though not the greatest from the standpoint of production. It covers about 94,000 square miles, lying to the west of the Ozark uplift and extending from northern Iowa and Nebraska southwestward 880 miles to central Texas. It has an eastern extension south of Ozarkis from central Oklahoma into Arkansas. The coals are soft humic and of paralic origin.

Wastage of Coal in Mining. — The amount of impure coal in nearly every coal bed in the United States varies from 10 to 50

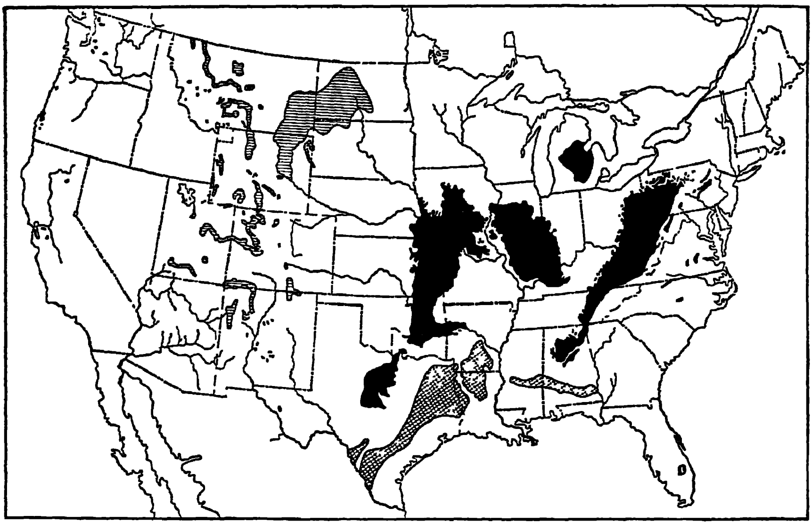

Fig. 138. — Known distribution of coal in the United States. Black areas, coals of Pennsylvanian age, except in Virginia and North Carolina, where the eastern areas are of Triassic time. Areas with horizontal lines, in the Rocky Mountains country, coals of Cretaceous age. Areas with diagonal lines, coals of Cenozoic time. U. S. Geol. Surv.

per cent, averaging 25 per cent. At present all of this is thrown away, though much of it could be used for the making of gas for gas engines. Due to faulty mining, bad engineering, the falling of roofs, "squeezes," "creeps," and "crushes," approximately another 30 to 40 per cent of the coal present in the mines is never taken out and is thus lost. In other words, about 40 to 70 per cent of the coal present is wasted or unused and never to be regained after the mines are abandoned. "If the wasteful methods of the past are to continue," says I. C. White, "if the flames of 35,000 coke ovens are to continue to make the sky lurid within sight of

the city of Pittsburgh, consuming with frightful speed one third of the power and half of the values locked up in these priceless supplies of coking coal, the present century will see the termination of the American industrial supremacy in the iron and steel business of the world."

Coal Production. — In 1912 the soft coal mined in the United States amounted to 450,000,000 short tons, valued at $518,000,000. The anthracite output of Pennsylvania for the same year was 75,000,000 tons, valued at $177,000,000. In 1913 three-quarters of a million men were employed in the mining of coal. From 1814 to the end of 1900 the United States had produced 4,470,000,000 short tons of coal, and by the end of 1914 the total had risen to 10,358,000,000 short tons. The total amount of coal in the United States within 3000 feet of the surface is estimated by M. R. Campbell as about 3,540,000 million tons. In Nova Scotia there are at least 7,000,000,000 tons of coal capable of being worked. The total quantity of coal available in the world is estimated by Gibson at about 11,801,000 million tons. Of anthracite in millions of tons there is about 500,000; of humic 3,903,000; and of sub-humic and brown coal, 7,398,000. In these estimates no allowance has been made, however, for coal not minable or for loss in mining.

In 1815, the year of the Battle of Waterloo, the world's entire output of coal was less than 15 million tons; a century later it was more than 1,300 million tons — an increase nearly a hundredfold. In 1913 the United States produced the greater amount of the world's coal output, 39 per cent, and used of it 37 per cent; Great Britain came next, with 22 per cent, of which she consumed 15 per cent; while Germany was third, having mined 21 per cent and consumed 19 per cent. For a manufacturing people, coal is at the basis of national prosperity. J. W. Gregory states that Great Britain has mined only about 6 per cent of its available coal, and that the supply will last at the present rate of consumption about 600 years. That of the United States and Germany will last these countries at the present annual yield for 1500 years.

Mineral Wealth of the United States. — The annual production of minerals throughout the world, according to C. K. Leith, is nearly 1,700,000,000 tons, and more than 90 per cent of this vast wealth dug out of the earth consists of coal and iron. Of all the minerals annually produced, about two thirds are used in the countries producing them, the remainder being exported as international exchange. How rich the United States is in mineral wealth is at once shown by the statement that this country produces one third of the

world's minerals (in 1913 the value was about $2,500,000,000); Germany less than 15 per cent; Great Britain 11 per cent; no other country more than 5 per cent. America is dependent upon other lands for its nitrates, potash, manganese, chromite, magnesite, tin, nickel, platinum, mica, graphite, asbestos, chalk, cobalt, etc., but nevertheless we are more nearly self-sustaining in regard to minerals as a whole than any other country.

The exportable coal of the world is controlled by North America, which in 1913 supplied about 40 per cent of the world's output, by England, and by Germany (Europe 54 per cent). In copper (65 per cent) and petroleum (roughly, 70 per cent) the United States dominates the world, and it is in addition a very important factor in the world's supply of sulphur (50 per cent), phosphate, silver, iron (38 per cent), and cement. We have of minerals an annual surplus for export amounting to about one billion dollars, and need to import annually about $175,000,000 worth. *It is these natural wealths that lead to world power in this age of industrialization.*

For a good account of the world's mineral resources, see the *World Atlas of Commercial Geology*, published by the United States Geological Survey in 1921.

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CHAPTER XXX

THE RISE OF LAND VERTEBRATES AND THE DAWN OF REPTILES

In the middle Paleozoic, and especially in the Devonian, when the dry lands had become fully clothed by plants — the substratum on which all animals are dependent for food — there was established a habitat capable of sustaining animal life, and destined to be mastered by worms, snails, spiders, insects, and other invertebrates, and finally by various groups of vertebrates. Among the latter, the first to find the land habitable were the ancestral Amphibia, and they ruled their various environments certainly from late Devonian until well into Pennsylvanian time. Out of these animals came more complex ones, a most wonderful variety of reptiles, which not only became lords of the lands, seas, and oceans before the close of the Permian, but shortly afterward invaded the air, and by their dominancy gave the Mesozoic or medieval world its title of the Age of Reptiles.

Amphibia, Living and Fossil

Amphibia differ from fishes in having legs and not fins, each leg bearing fingers or toes. Nearly all of them breathe by gills when very young and may retain these organs throughout life; lungs and functional nostrils are, however, nearly always present in the adult, although among the salamanders lungs may be reduced to vestiges or completely suppressed (see Pl., p. 407, Figs. 1–4). They have a three-chambered heart, and a mobile muscular tongue.

Living Amphibia. — There are about nine hundred forms of living Amphibia, most of which are of the frog kind (Fig., p. 406). Frogs, toads, newts, sirens, mud-puppies, water-dogs, and land salamanders are types of living amphibians (Pl., p. 407). All are cold-blooded animals. The class name Amphibia, which means *living a double life*, was given them because many live both on the land and in the fresh water. Others, however, live entirely in the water, and, as a rule, all amphibians in their younger stages are wholly restricted to this element.

The sexes are always separate and in the great majority of species the small eggs are fertilized in the water and develop there

without further care from the parents. The development is, therefore, very much the same as in the fishes and very unlike that of the higher vertebrates. The eggs of frogs and toads, for example, develop into little animals commonly known as tadpoles or polliwogs, with a more or less large and rounded head and body terminating in a long and very flexible tail, which they wriggle in swimming, as do the fishes (see Fig., below). These tadpoles have gills which at first project from the sides of the head, but are later covered by an operculum. In about two months they attain a stage which is the equivalent of the lung-fishes. They then undergo

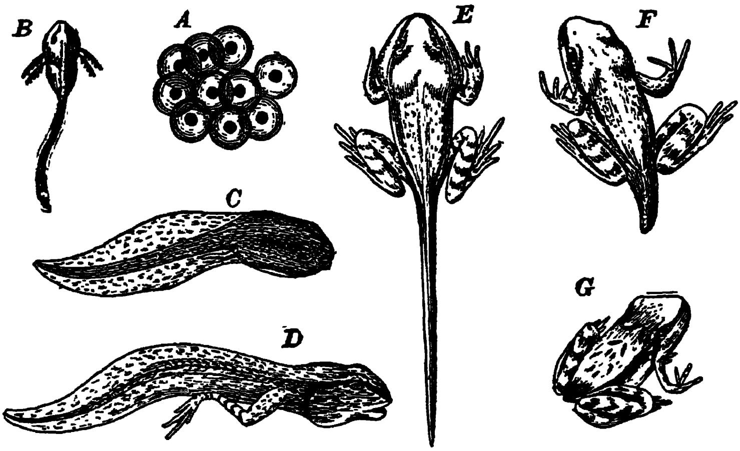

Fig. 139. — Development of the frog (*Rana temporaria*). *A*, eggs, greatly enlarged; *B*, tadpole or polliwog, with two pairs of gills; *C*, tadpole with first indication of hind legs; *D*, older tadpole; *E*, tadpole with both pairs of legs free; *F*, *G*, stages in which the tail is resorbed. Redrawn from Leuckart's wall charts.

a marked metamorphosis, the hind legs appearing first and later the front pair, which are hidden under the operculum. The long tail shortens through internal absorption and the gills are also absorbed or drop off. The lungs then appear, and for a time the young creatures are fully amphibious, breathing water through their gills and extracting the free oxygen from it, and also taking in air through the lungs; but soon the small frogs or toads take to the land and breathe air only (see Fig., above). In this metamorphosis, requiring from a few weeks to at most a few months, we see a recapitulation of Paleozoic history that consumed millenniums of selection of the most fit for their environment. In those forms that remain permanently in the water the transformation is not so great, and some of them resemble fishes in bodily form through-

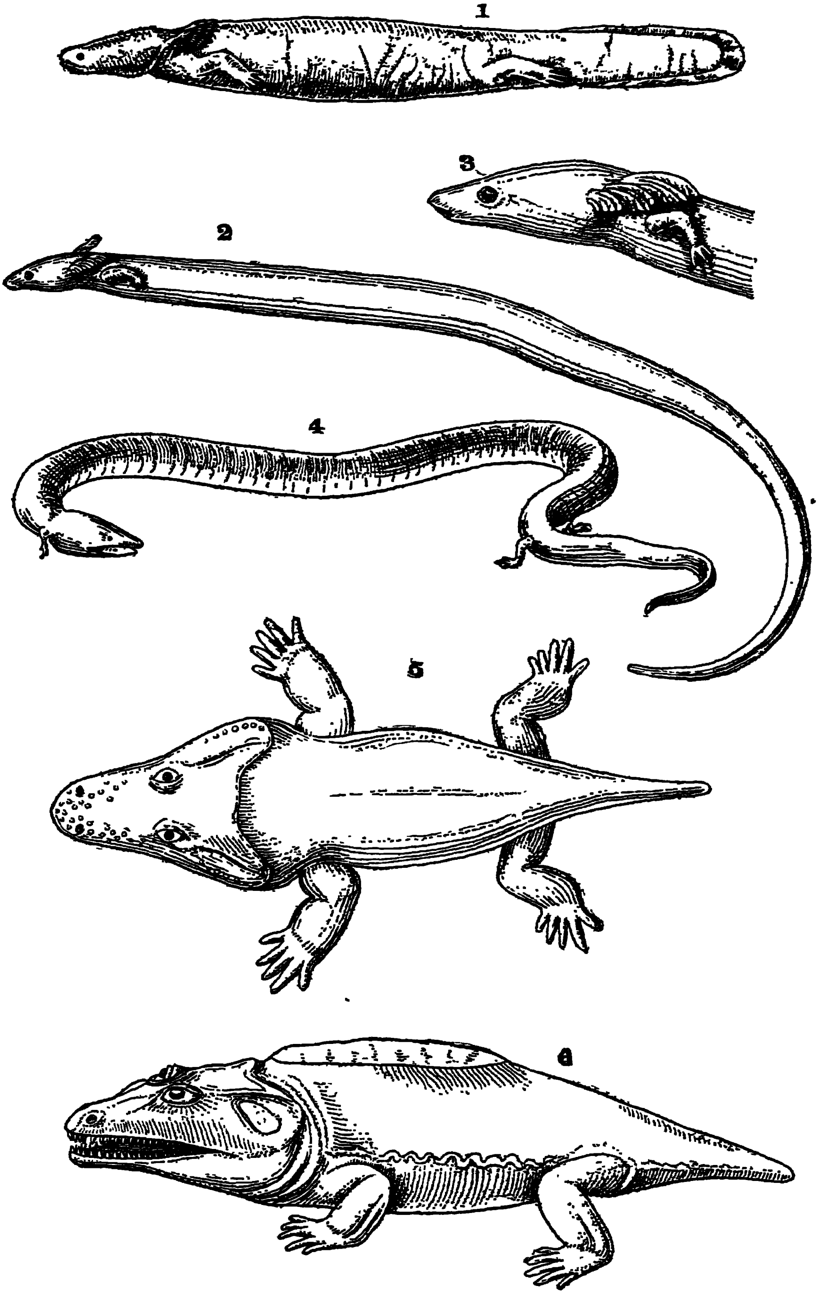

Plate 30. — Amphibia. Living tailed Urodela (1–4) and Permian stegocephalians (5, 6).

Fig. 1, mud-puppy (*Necturus maculatus*) of the Ohio and Mississippi rivers; 2 and 3, *Siren lacertina*, a small salamander, note the three pairs of gills and the absence of hind legs; 4, *Amphiuma tridactyla*, with both gills and lungs; 5, *Trematops milleri*, a stegocephalian, 3 feet long, from Texas; 6, *Cacops aspidephorus*, a stegocephalian, 20 inches long, from Texas. Figs. 1 and 4 from Parker and Haswell; Figs. 2 and 3 after Lankester. British Museum Guide Book; Figs. 5 and 6 after

out life, among these being the so-called mud-puppies and water-dogs common to the rivers of the Ohio and Mississippi valleys (see Pl., p. 407, Fig. 1).

Respiration. — All Amphibia in their youth are provided with two or three pairs of external gills or internal ones with external gill-clefts, soft feathery outgrowths situated at the back part of the head and rich in blood-vessels (see Pl., p. 407, Figs. 1–3). Such gills are also present in the lung-fishes, and in the sirens and mud-puppies they may persist throughout life, though this condition is rather exceptional. In the salamanders of the land, and in all of the tailless Amphibia (frogs, etc.), the gills disappear and adult respiration is carried on wholly by lungs, as in the higher vertebrates. While the gills are present, the air passages to the lungs through the nose do not open into the mouth, but assume this position as soon as the gills vanish and the lungs become functional. The air is then taken in through the nasal openings and in the frogs is forced into the lungs in a swallowing manner. Many of the Amphibia can live a long time without food, and in the colder countries all the land forms hibernate through the winter in the mud at the bottom of streams and ponds, breathing during this time only through the skin.

Hearing. — In none of the fishes are there functional ears, though there are internal ones; in the amphibians, however, there are distinct external organs of hearing. These are best seen in the frogs, where the tympanic membrane of the ear-drum is a more or less large, circular disc embedded in the outer skin on the sides of the head. The cavity behind the disc, or drum, connects with the back part of the mouth by a tube known as the Eustachian tube, which is also present in all of the higher vertebrates.

Classification. — The living forms are divided into two subclasses on the basis of their body form: when tailless in the adult stage, they are called *Anura* (without a tail, see Fig., p. 406), while the primitive forms retaining the tail are called *Urodela* (having a distinct tail, see Pl., p. 407, Figs. 1–4). The Paleozoic amphibians, to be discussed later, are included under the term *Stegocephalia.*

The *Anura* include the frogs and toads so commonly known. They always have four legs, the hind pair of which are long and powerful, and the adults are without external gills or gill-clefts. They are almost cosmopolitan, occurring in all countries except the cold polar regions. This subclass is of comparatively modern origin, since the oldest fossil form is known in the late Jurassic, though in Cenozoic strata they occur far more frequently. They are the

most diversified of living Amphibia, and also the most specialized, but are not of particular interest in Historical Geology.

The *Urodela* or tailed Amphibia are of far more significance in this connection, and even though fossil forms are not known older than the Jurassic, the subclass must have had its origin in the Paleozoic Stegocephalia. The Urodela, now practically restricted to the temperate parts of the northern hemisphere, are amphibians which as adults (salamanders, tritons, sirens, mud-puppies and axolotls) are often strikingly fish-like in appearance (see Pl., p. 407, Fig. 1). In the mud-puppies and axolotls there is an unpaired fin on the dorsal side, continuing around the diphycercal tail and along the posterior part of the ventral side, as in the lung-fishes. However, this fin does not have skeletal or bony rays, as in the fishes. Even though the Urodela are fish-like in appearance, they are readily distinguished by the fact that their paired appendages are not fins but fully developed legs, though small and weak, with all of the essential skeletal characteristics of the limbs of the higher vertebrates (study Pl., p. 407, Figs. 1–4). As a rule, there are two pairs of these limbs, the front or pectoral, and the hind or pelvic. In some forms, however, only the anterior pair is present, the posterior one having been lost, and in a few species all of the limbs are absent, these latter being the burrowing, worm-like Cæcilians of tropical lands. The number of toes on each foot varies between five, the usual number, and two. Some forms, like the land salamanders, when matured may live wholly on the land and lose all trace of the gills, while others, such as the mud-puppies, remain in the water and preserve the gills throughout life. The Japanese and Chinese giant mud-puppy is the largest of all Urodela, attaining a length of 5 feet. One individual lived in captivity for over fifty years.

Stegocephalia, the Paleozoic Amphibia. — The term Stegocephalia means *covered* or *mailed head* and has reference to the fact that the upper surface of the actual skull was roofed over by more or less thick dermal bones. They are also known as the solid-skulled and armored Amphibia, and it is this armoring that at once distinguishes the Paleozoic and Triassic forms from all living ones. The chest was likewise provided with dermal armor, consisting of three large sculptured plates which represented a part of the bones of the pectoral arch of the fishes and the shoulder girdle of higher vertebrates. In some forms the entire body was covered with small overlapping scales, those of the ventral side being the thickest, or the scales being on the ventral side alone, while others (Branch-

iosauria) were essentially naked and devoid of scales. Nearly all living Amphibia are naked and scales are but rarely present (Cæcilians.) One group of the ancient forms have been called *Labyrinthodonts*, because the dentine of the large and conical teeth was much folded in labyrinthine undulations such as are first seen in fishes (p. 298).

The first trace of a limbed vertebrate, probably stegocephalian-like, is a foot impression (*Thinopus*) from the Upper Devonian (Fig., p. 331), but skeletons of the armored amphibians are not known in North America until Pennsylvanian times. They were then and in the Permian in their heyday. The whole stock vanished before the close of Triassic time.

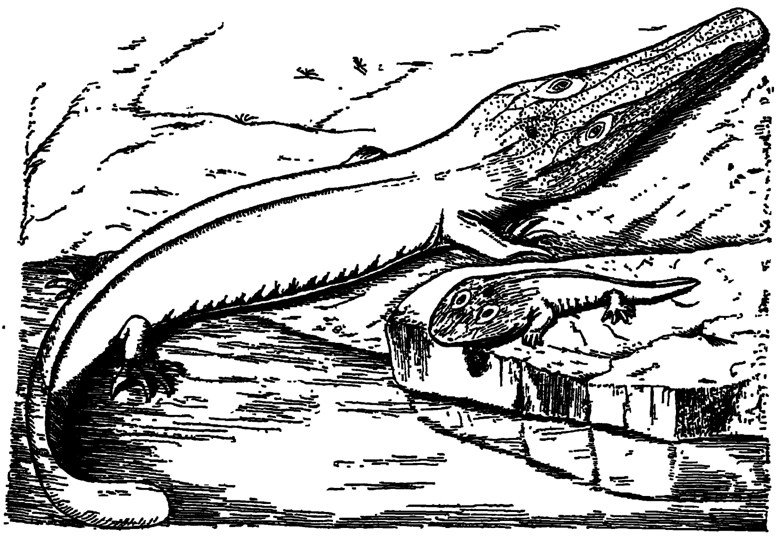

Fig. 140. — One of the larger Stegocephalia (*Archegosaurus*), 5 feet long, with a heavily armored skull; and a small tadpole-like form (*Branchiosaurus*), 6 inches long. Note the third or pineal eye. Lower Permian of Germany. From Museum Guide of the University of Tübingen. For other forms, see page 407.

The most primitive Amphibia had small heads and weak limbs on long bodies that terminated in propelling tails like those of modern salamanders, but unlike these retained more or less of the bodily armor that came to them from their scaled and armored fish forebears. The large-headed forms seen chiefly in the late Pennsylvanian and early Permian were precocious descendants of primitive forms. The marked evolution of the ancient amphibians falls in with the time of their deployment into all the varied environments, passing from water and swamp habitats to transitional ones, and finally to those of the dry lands, and here becoming still more diversified

by burrowing beneath the surface and rising above it into the trees.

There are many kinds of stegocephalians known, the Coal Measures of North America alone yielding ninety species. In size they range from about an inch to more than 10 feet (Fig., p. 360). Some were lizard-like, small and active, with well-developed walking legs and relatively short tails; some were active swimmers, with long tails; others of medium size were thick-set and sluggish in habit, like the crocodiles (Fig., p. 410); while a few had the appearance of being gigantic, almost legless, tadpoles wriggling about in the water. A tail was invariably present.

In the great majority of Stegocephalia there were two pairs of limbs, though leg-less forms like snakes are also known (see Fig., p. 360). The limbs were well developed but short and stumpy (see Fig., p. 410, and Pl., p. 407, Figs. 5, 6). The bones of the front legs were like those of living salamanders in number, form, and disposition, and the hands were provided with four, or rarely five, usually short fingers. The hind limbs were nearly always longer and heavier, and bore five toes, of which either the second or third was the longest.

The heads were often broad and flat, with very wide mouths almost the full width of the skull, as in frogs and salamanders; but in some forms the heads were more or less elongated and even pointed, as in crocodiles. The heads of the latter, however, are also broad in the young stages, so that the broad head must be the primitive type. Of the former kind, *Eryops* of the Permian of Texas had a head 2 feet long and 18 inches wide and resembled a huge tadpole with a wide flat head, no neck, a thick heavy body, short legs, and a heavy flattened tail (see *Branchiosaurus*, Fig., p. 410). As Huxley has said, they " pottered with much belly and little leg, like Falstaff in his old age, among the coal-forests."

The Stegocephalia probably all lived either in fresh water or on the dry land, and some fed along the beaches of the Triassic seas. Certain of the small, active types are found in hollow logs of the Pennsylvanian of Nova Scotia. Probably the great majority of Stegocephalia were carnivorous and fed on shell-fish, worms, and other water invertebrates, but more particularly on fishes, reptiles, and small members of their own tribe.

The Third Eye of Stegocephalia. — In all well-preserved stegocephalian skulls the armor or roof bones and those of the true skull were pierced not only by the large lateral orbits in which the paired eyes were situated and by the pair of anterior nasal openings, but also by a single small orifice through the bone over

the brain (see Fig., p. 410). This aperture is of great interest, for in it was situated a third eye known as the *pineal eye*. Such an opening is also found in many fossil and some living reptiles (*Sphenodon*), and while the organ it contains can hardly be regarded as acting like a true eye in living reptiles, its great significance lies in the fact that it is a vestigial organ whose ancestry can be traced back at least to Pennsylvanian time. The rudiments of this eye are present in the brain of all living vertebrates, including man.

Ancestry of Stegocephalia. — It is becoming increasingly difficult to distinguish the late Paleozoic reptiles from their stegocephalian associates. The most ancient of the solid-headed reptiles (Cotylosauria and Pareiasauria) are very similar to the solid-headed Stegocephalia. Of this type Osborn says: "Bone by bone its parts indicate a common descent from the skull type of the fringe-finned fishes (Crossopterygia)." In other words, evidence is rapidly accumulating to show that the stegocephalians were not the most primitive limbed land vertebrates, but that they arose in an older stock (Protopoda), which gave rise on the one hand to the water-loving amphibians, and on the other to the reptiles, which became completely adapted to the dry land.

Reptilia, Living and Fossil

In all of the vertebrates so far studied — fishes and amphibians — we have seen that their habitat is either wholly in the water, or that at the very least the small eggs are there laid and fertilized, and that the young are also born and spend the days of their youth in this element. All of the higher vertebrates remove themselves more and more from this habitat and none are developed in it directly from the egg. In other words, the reptiles, as a rule, are oviparous, laying *large* eggs like those of birds and provided with a more or less great quantity of food (yolk), and these eggs are fertilized before they are laid upon the land, where they hatch under the warmth of the sun. This is the most important and fundamental difference between the lower vertebrates, the fishes and amphibians on the one hand, and the higher vertebrates, the reptiles, birds, and mammals, on the other.

Living Reptiles. — All of the living animals known as turtles and tortoises, lizards and snakes, alligators and crocodiles, and the extinct types, the giant dinosaurs of Mesozoic time and the flying reptiles called pterodactyls, belong to the class Reptilia. The word *reptile* means *creeping* or *crawling* and has reference to an animal that goes on its belly like the snake, or moves with difficulty on short sprawling legs, like the alligator. There are, however, many reptiles that are in no sense creeping and crawling animals, as, for instance, many of the fleet-footed lizards, certain of the dinosaurs with their pillar-like legs, and the winged pterodactyls.

All living reptiles are cold-blooded animals like the fishes and amphibians, and their skin is never soft, but always more or less

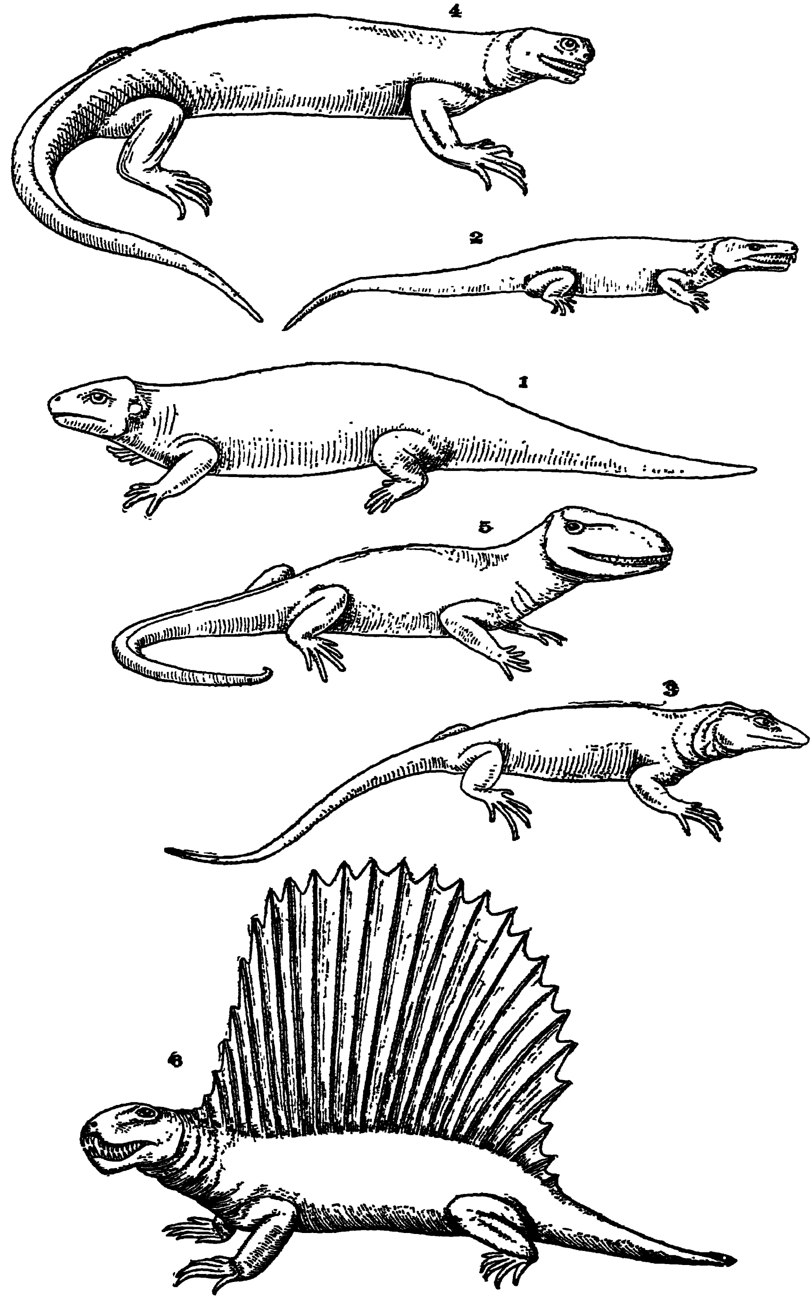

Plate 31. — Permian reptiles from Texas and New Mexico. 1, 2, cotylosaurs; 3–6, pelycosaurs.

Fig. 1, *Diasparactus zenos*, about 7 feet long, from New Mexico; 2, *Limnoscelis paludis*, about the same length and from the same state. Fig. 3, *Varanosaurus brevirostris*, an agile form, nearly 4 feet long, from Texas; 4, *Casea broilii*, of about the same length and from the same state; 5, *Ophiacodon mirus*, about 7 feet long, from New Mexico; 6, *Dimetrodon*, about 8 feet long, from Texas. All after Williston.

hardened by horny or bony material that occurs more often as scales than as armor plate. Even though many reptiles spend a large part of the time in the water, they are essentially land animals, as they are born on the land and breathe exclusively through lungs. Each animal has a pair of lungs, but in the elongated snakes the left lung is rudimentary and almost lost. In the snakes and in some lizards, legs are either wholly absent or mere vestiges buried in the flesh, and in such reptiles locomotion takes place by means of a wriggling movement either over the ground or through the water. Wherever legs are present, the fingers and toes have claws, a feature that is very rare among Amphibia.

In many of the reptiles eyelids are present, and in most lizards and fossil reptiles there is also the pineal eye. The organs of smell and hearing are also well developed, but in the reptiles the vibrating, or tympanic, membrane of the ear-drum is no longer external, as in the frogs, but lies in a depression. With the exception of the turtles, nearly all reptiles have teeth; in living forms these are usually pointed and often recurved to serve for the holding of their animal prey. In many fossil forms, however, the teeth were adapted for cutting and more rarely for the mastication of food. In snakes and some lizards the tongue is slender and bifurcated and is protruded in a darting manner. In other reptiles the tongue is flat and immovable, as in crocodiles, being then attached to the floor of the mouth.

Development of Reptiles. — In some living lizards and snakes, and rarely among extinct forms, the females are viviparous, that is, they give birth to fully formed, living young. The great majority of reptiles, however, are oviparous. The eggs resemble those of birds, but are, as a rule, rounder and have a tough, parchment-like, porous covering, or in some cases a calcareous shell. As these eggs are very different in their development from those of fishes and amphibians, they need to be described in more detail.

Since the eggs of reptiles are large and develop on the dry land, they must naturally be very different in internal structure from the small ones of amphibians which hatch in the water. In the latter the embryos have functional gills for use in the water, but in the reptiles a wholly different organ has been originated to provide the developing young within the egg with the necessary oxygen. This sac-like embryonic organ, known as the *allantois,* passes on to the embryo the oxygen received through the porous shell, and carries off by the reverse process the carbonic acid gas; in other words, its function is respiratory (see Figs. *A–E,* p. 415).

"The unhatched or unborn reptile breathes by means of a vascular hood spread underneath the eggshell and absorbing dry air from without. It is an interesting point that this vascular hood, called the allantois, is represented in the amphibians by an unimportant bladder growing out from the hind end of the food-canal. A great step in evolution was implied in the origin of this ante-natal hood or fœtal membrane and another one — of protective significance — called the amnion, which forms a water-bag over the delicate embryo. The step meant total emancipation from the water and from gill-breathing, and the two fœtal membranes, the amnion and the allantois, persist not only in all reptiles but in birds and mammals as well" (J. A. Thomson in *Outlines of Science*).

Reptile eggs are large and contain a great deal of yolk, on which the embryo lives and grows. At one pole of the egg lies the fertilized germinal vesicle which develops into the embryo (Fig. *A*, opposite). During its earliest growth there is formed at either end of the elongate embryo a two-layered, crescent-shaped fold, called the *amniotic fold*, which arches over the embryo and finally unites to cover it with a pro-

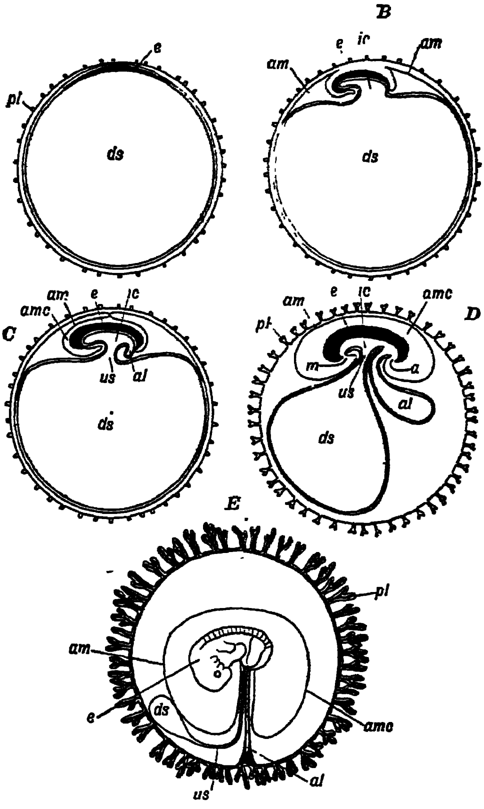

Fig. 141. — Generalized diagrams of a growing mammal egg sectioned to illustrate the fœtal organs in birds, reptiles, and mammals (Amniota). *A*, ovum with embryo just beginning to develop; *B*, somewhat older stage in section, with earliest stage of the forming amnion (*am*); *C*, ovum with amnion closing, and allantois (*al*) appearing; *D*, embryo with mouth (*m*) and anus (*a*); *E*, later growth, with fœtus more fully developed.

a, anus; *al*, allantois; *am*, amnion; *amc*, amniotic cavity; *ds*, cavity of embryonic vesicle, later the yolk sac; *e*, embryo; *ic*, intestinal cavity; *m*, mouth; *pl*, placenta, an organ found only in mammals, formed of the walls of the uterus and embryonal membrane; both are abundantly supplied with blood-vessels, and while there is no direct continuity in the two blood streams, nutrient materials and respiratory gases are exchanged by osmosis; *us*, umbilical stalk. After Kölliker.

tective hood. This latter is the *amnion*, and between it and the embryo there is a shallow cavity containing a watery *amniotic fluid*, bathing and protecting the outer surface of the embryo (Fig. *B*, p. 415). As the amnion occurs only in the eggs of reptiles, birds, and mammals, these groups are known collectively as the *Amniota*, and the fishes and amphibia, which lack it, are called *Anamnia*, meaning *without the amnion.*

Paleozoic Reptilia. — Most of the Pennsylvanian and early Permian reptiles were plump, sluggish, more or less sprawling animals, basking often on the land in the hot sun. In many ways they still resembled the stegocephalians, their associates, but had a marked tendency toward a reduction in the size of skull and toward loss of body armor. In all the forms the feet terminated in five fingers or toes. Few appear to have been swift of foot, and some, the "ship lizards" or "fin-backed lizards," bore a curious, very high, dorsal, median crest (Pelycosauria, Pl., p. 413, Fig. 6). "These structures" says Osborn, "may have developed through social or racial competition and selection within this reptile family rather than as offensive or defensive organs in relation to other reptile families." Most of the late Paleozoic forms were fierce-looking animals because of their large, recurved, holding teeth, and all of the American representatives seem to have been carnivorous in habit, feeding on insects, armored fishes, armored amphibians, and other reptiles. Others had crushing teeth, indicating a diet of shell-fish and crustaceans.

Osborn says that the environment which changed the primitive Amphibia of the late Paleozoic into the Reptilia of the Permian was a warm, terrestrial, and semi-arid region, favorable to the development of a sensitive nervous system, alert motions, scaly armature, slender limbs, a vibratile tail, and the capture of food both by sharply pointed recurved teeth and by the claws of a five-fingered hand and foot. This evolution is as marvellous and extreme as the subsequent one of the mammals. Before the close of the Permian the reptiles had mastered all the parts of the lands, and were taking possession as well of the waters of the lands and seas.

It seems probable that the Reptilia arose even earlier than earliest Pennsylvanian time, for in the latter part of this period occurred not only true reptiles but also highly specialized forms. From the Pennsylvanian and older Permian of Texas, Oklahoma, and New Mexico, Williston and Case have made us acquainted with many different kinds of primitive Amphibia, and associated with them is even a greater and more complex society of prim-

itive Reptilia, animals that attained a maximum length of 8 feet (see Pl., p. 413).

The order Cotylosauria embraces the solid-skulled reptiles, so called because the head was armored with sculptured plates (Pl., p. 413, Figs. 1, 2). They were the most primitive of reptiles. In build they were low and stout, slow of movement, and clumsy in walking, but since they had rather long tails, they swam well. All were carnivorous, though some fed partially on plants. Their life range was from late Pennsylvanian to late Triassic, and they are known chiefly in North America and Europe, though some occur in South Africa.

The order Theromorpha (means wild beast), which includes the Pelycosauria ("fin-backed lizards"), was a highly specialized group of wholly land-living forms. They were active and lizard-like, with rather long tails, and some among them attained to a length of 8 feet. The "fin-backed lizards" were plump and bore a more or less high dorsal bony crest or fin. All were fiercely carnivorous. Their life range was from late Pennsylvanian into late Permian and they were in greatest abundance in North America, and less common in Europe and Africa.

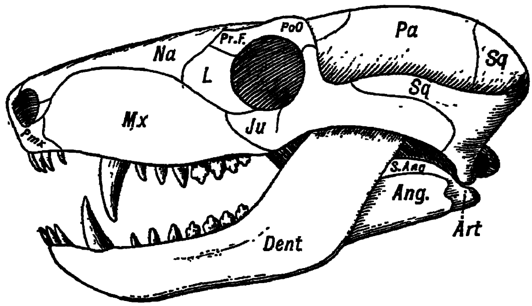

Fig. 142. — A theriodont reptile skull, about 4 inches long, from the Triassic of South Africa, showing primitive mammalian type of teeth. After Broom.

South Africa is another region in which are preserved many excellent skeletons of ancient amphibians and reptilians. They occur commonly in the very thick Karoo series (up to 9500 feet) of continental shales and sandstones, and of Permian and Triassic times. According to Osborn, the greatest number of forms are found in the early and middle Permian, when the world already had a wonderful society of reptiles.

This African reptile assemblage included great round-bodied herbivorous forms (pareiasaurs), having massive limbs and round solid heads; agile ones with large eye-sockets and adapted to swift running (dromosaurs = running reptiles), "terrible reptiles" with mammal-like heads (Theriodontia = carnivorous teeth), and many slender-limbed predatory types with sharp canine-like teeth. There were also giant carnivorous reptiles (dinocephalians = "terrible headed"), very massive animals with a highly arched back, broad swollen forehead, and short wide jaws provided with marginal teeth. Surpassing even these in size were the "lawless toothed reptiles" (anomodonts), in which the skull ranged from

a couple of inches to a yard in length, and the jaws were sheathed in horn and hooked like those of turtles. Finally in the early Triassic appeared the "dog-toothed" reptiles (cynodonts), the most mammal-like of all.

Progenitors of Higher Reptiles. — As has been said, the most primitive reptiles are the Cotylosauria. Lull tells us that this order, as seen in *Limnoscelis* (Fig. 2, p. 413), may well have been the central stock out of which could have evolved directly or indirectly the lizards, alligators, and dinosaurs. The cotylosaurians were swamp-living, sluggish, long-tailed reptiles having four legs of equal proportions.

Progenitors of Mammals. — In the Permian and Triassic of Africa and North America are found carnivorous reptiles of the suborder Theriodontia. They range in size from small forms to those as large as a tiger. They are of great interest because the African forms are regarded as having given rise to the lowest or egg-laying mammals, while in the American forms originated the higher reptiles. Their teeth were differentiated and localized, as in mammals, into incisors, canines, and molars (see Fig., p. 417).

Collateral Reading

E. C. Case, The Permo-Carboniferous Red Beds of North America and their Vertebrate Fauna. Carnegie Institution of Washington, Publication No. 207, 1915.

E. C. Case, The Environment of Life in the Late Paleozoic in North America; a Paleogeographic Study. Ibid., Publication No. 283, 1919.

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CHAPTER XXXI

PERMIAN TIME AND ITS GLACIAL CLIMATE

History of the Term Permian. — When Murchison through his great classic *Siluria* had become widely known as the great leader in Stratigraphy, he was asked by the czar to study the geologic sequence of western Russia and chiefly of the Ural Mountains. In this work he was associated with Keyserling of Russia and De Verneuil of France. Their studies led to the discernment of a distinct series of highly fossiliferous marine and brackish-water formations that lay above the Coal Measures and beneath the Triassic. These were found well exposed along the western flank of the Urals in the Province of Perm, and using this geographic term Murchison proposed in 1841 to include them under his new term *Permian system*, which has now come into universal use.

The actual significance of the Permian of the Urals was, however, not clear until long afterward, and as late as 1903 we read in Sir Archibald Geikie's text-book that "no satisfactory scheme of subdivision of the Permian system has yet been devised capable of general application." We are, in fact, only now approaching this desired end. In Murchison's time, the strata of Artinsk (southern Urals), lying below the typical Permian, were thought to be of Coal Measures age, and it was only toward the close of the nineteenth century that they were successfully referred to the Permian. A clearer understanding of the significance of the Permian of the type area gradually came through the determination of the longest sequence anywhere of these formations, that in the Salt Range of India. These strata were gradually correlated on the basis of fossil content with those of the Urals and more especially with those of the northern Mediterranean, which have a variety of widely dispersed ammonites, the best of fossils for correlation. During the past decade these shells have also been collected in Texas and elsewhere in the United States, and due especially to the studies of G. H. Girty and Emil Böse, the American equivalents of the Permian now appear to be satisfactorily correlated with the formations of India and Russia.

Following in the main the work of Böse, the Permian of North America may be classified as shown on page 421.

Most Significant Things about the Permian. — The Permian is the closing period of the Paleozoic era, and with the close of the Lower Permian all of North America was dry land. There is in our continent no record of Middle and Upper Permian times other than of erosion, but as to the importance of this erosion little is to be gleaned from the unconformities between the Permian and subsequent formations.

Almost all of the Lower Permian formations occur in the Central Interior and southern Cordilleran regions of the United States. The marine waters that laid down these deposits came from the Pacific across northern Mexico; they were normally marine toward the south and west, but their northern and eastern extensions spread vast sheets of red beds that have thick deposits of gypsum and salt. It was an epeiric sea surrounded by desert conditions, and the brackish-water phase, the red beds, entombed in places a wonderful series of reptiles and amphibians.

The marked mountain making of the Pennsylvanian was continued into the Permian, and culminated with the making of the Appalachians, the Ouachitas, and the Ancestral Rocky Mountains. With the recession of the epeiric seas, there came in during the last third of Lower Permian time a glacial climate that was of greatest import in the southern hemisphere, and seemingly one as cold as, or colder than, that of the Pleistocene. The stress climate of the Permian, and chiefly of the southern hemisphere, warmed later to more equable ones, but over most of the earth the widely emergent continents still produced more or less of dry and desert conditions. In North Europe the last of the Permian seas laid down very thick red deposits, along with tremendous amounts of salts and gypsum, all of which testify to the arid conditions so prevalent during the closing period of the Paleozoic.

The glacial climate and the subsequent long-continued arid conditions wrought a mighty change in the life, both of the lands and oceans. We have seen that for a long time before the Permian the climates had been mild the world over, and that "no animal could endure the least cold." Accordingly the Permian was an age of hardship and struggle for all life, and brought death to many of the specialized stocks. With the glacial climate, there came into existence a hardier flora in the southern hemisphere known as the *Gangamopteris flora,* which in later Permian time had in Asia spread to the Arctic Ocean. This flora provided a different, and probably a better food for the insects and reptiles of the land, and accordingly we see a marked evolution among them. In the seas there was a

TABLE OF PERMIAN FORMATIONS

	North America						Urals	India (Salt Range)
Upper Permian or Thuringian (Upper Zechstein. Red beds)	Not represented in America Time of salt making						Break Red beds	Upper Productus: Break Chideru stage Kundghat Jabi
Middle Permian or Saxonian (Middle and Lower Zechstein)	Not represented in America						Typical Permian	Mid. Productus: Kalabagh Virgal
	Glass Mts., Texas	Guadalupe, Texas	Central Texas	Oklahoma	Kansas	California	Break	Lower Prod.: Katta Amb
Lower Permian or Guadalupian	Break Late: Tessey-Gilliam Vidrio Word Leonard Early: Hess Break Wolfcamp	Break Capitan-Rustler- Castile Delaware Hueco Hueco	Break DoubleMt. Clear Fork Albany Wichita	Break Quartermaster Woodward Blaine Enid	Break Cimarron Wellington Marion Chase Council Grove	Break Robinson Nosoni -McCloud -?Calaveras Break	Upper dolomite of Artinsk: Upper Arta and Kungur Break: Lower Arta Break	Ice Age: Speckled sandstone Tillites (Talchir, etc.) Break

great dying out of many kinds of brachiopods (chiefly productids and orthids), tetracorals, ancient echinids, and fusulinids, and the scattering trilobites also vanished. Their places were taken by the ammonids, lobsters, and modern echinids and molluscs. Just as the river fishes of Silurian time had peopled the seas, so now the land reptiles (*Mesosaurus*) began to take to this habitat, and this early adaptation is a prophecy of the many kinds of marine reptiles that were to flourish in Mesozoic time.

American Seas

Central Interior Region. — By far the best known sequence of American Permian formations is that of Texas, where they appear to continue the Pennsylvanian strata without a marked break. In the central and northern part of the state they are of the red beds phase, and as such are continued north across central Oklahoma and Kansas into eastern Nebraska. In the north these deposits are not thick and are of brackish-water origin, thickening more and more into Oklahoma and Texas, where toward the west the sandstones, sandy muds, and clays are dominantly red in color and abound in vast quantities of gypsum. In fact, Oklahoma is known as the Gypsum State. There is also in places considerable limestone and dolomite. In Texas the thickness is variable up to 5400 feet and the clastic materials appear to be derived from the rising Ancestral Rocky Mountains in Colorado and New Mexico. They are vast tidal flat and river deposits of an arid climate, spread eastward into the epeiric seas that came over the continent from the south and west. In north-central Texas the Permian is in places replete with a wonderful array of land reptiles. (See Map 4, p. 355.)

The red color and the presence of gypsum and salt are the striking phenomena of the latest Pennsylvanian and early Permian deposits of the southwestern United States. With the retreat of the Pennsylvanian seas and until their return in Europe in the Middle Permian, the brackish- and fresh-water formations are as stated, and these conditions are interpreted as due to dry climates, evaporating the water, precipitating the salts, and oxidizing the sediments.

Southern Cordilleric Seas. — The north-central Texas Permian strata are continued westward beneath later formations, and when they reappear at the surface in the Glass and Guadalupian mountains in the southwestern part of the state, they are a very thick series of limestones (4800–6800 feet) and sandstones (2000 feet), probably averaging about 7000 feet in thickness. At the top there are again

red beds with gypsum, about 500 feet thick, but this phase of the deposits thickens toward the north to constitute the widely spread red beds of the Great Plains country. This brackish- and fresh-water phase also continues across central New Mexico north into Wyoming, while the marine character is more dominant over Arizona north into Nevada and Idaho. In the Grand Canyon of the Colorado may be seen a fine exposure of Permian strata and as well a great valley cut down through the entire Paleozoic to the old floor over which these seas wandered for so long a time (see Frontispiece).

In northwestern California the Permian is also known, but nowhere else along the Pacific border. (See Map 4, p. 355.)

Dunkard Series. — In southeastern Ohio, southwestern Pennsylvania, and adjacent parts of West Virginia, the Pennsylvanian formations are continued without interruption into the Dunkard series of earliest Permian time. These are also known as the Upper Barren series, because the Dunkard has but little of commercially valuable coals. They are the last Paleozoic deposits of eastern North America. Of them there still remain, over an area of 8000 square miles, sandy shales with persistent sandstones, and thin limestones, variable in thickness from 600 feet of dominantly red beds in Ohio to about 1200 feet of greenish and red beds in West Virginia. That the southwestern sea did enter this area, at least for a limited time, is attested by the presence of marine brachiopods (*Lingula*) and shark spines. The Dunkard abounds in land plants, and in the Cassville beds 107 species of these are known, along with many wings of cockroaches.

Vanishing of the Paleozoic Epeiric Seas. — We have seen that during later Pennsylvanian time a very shallow sea, coming in from the south and west, spread in an oscillating way across the United States as far as central Pennsylvania. These waters began to ebb toward the close of this period, though brackish waters were to some extent still present in earliest Permian time in southeastern Ohio, as attested by the sharks of the Dunkard formation. A very little fresh-water Permian is also known near Danville, Illinois, filling an ancient river valley. Otherwise no rock-making records of this period are known throughout the eastern half of North America, and we shall see that *this widely emergent condition continues here to the present time.*

With the making of the mighty Appalachian Mountains and the permanent withdrawal of all seaways, the many domal and axial uplifts of the Great Interior were again upwarped. It was upon this rejuvenated topography that the present drainage system came

to be developed, wearing away the later Paleozoic formations from the higher places and so exposing here the older ones, and levelling all into a vast peneplain. This levelled land during Mesozoic and Cenozoic times lay nearer sea-level by a few hundred feet than it does now, and the renewed scouring of the present rivers is due to wide and gentle uplifts that occurred late in Pleistocene time. We shall see in subsequent chapters that the making of later geologic records in the main is restricted to the greater western half of North America and to a very limited area along the Atlantic and a somewhat wider one along the Gulf of Mexico border of the United States.

Vast Salt-making Areas of the Permian. — In previous pages attention was directed to the red beds of vast extent in the southern and western interior regions of this country. Such widely spread red formations indicate the presence of arid or desert climate, and we have now to consider the evidence which clinches the argument for general Permian aridity.

In central Kansas at Hutchinson and Lyons, salt has been mined for some years, and Darton has recently informed us that the salt deposits here have a thickness of between 200 and 400 feet in an area of at least 7000 square miles. It is interesting to note that our knowledge of these salt beds has been largely revealed in the search for petroleum. The time of the making of these salt beds was early Permian (upper Marion). The evidence as presented by Darton indicates that the known extent of the salt in this area covers at least 100,000 square miles, with an average thickness of 200 feet, making the gross quantity about 30,000 billion tons. The prediction is made that much potash for fertilizers will also be obtained here. It is the largest salt area of the world, exceeding even that of Germany in younger Permian time.

Over the greater part of North Germany occur the Middle and Upper Permian limestones and dolomites known as the Zechstein, and twice the sea which deposited these was converted into vast salt-making basins. Each salt series, in its best development, begins with gypsum (anhydrite), passing into thick deposits of sodium chloride and finally into magnesium and potash salts. It is the region of most complete sequences of salt precipitations, and has made Germany not only the richest nation in table salt but more so in potash fertilizers. Kayser in his well known *Lehrbuch der geologischen Formationskunde* says that the salts between Wesel and Ruhrort have a thickness of 420 feet, at Hohensalza of 585 feet, Kaiseroda 740 feet, Stassfurt 3000 feet, Aschersleben 1600 feet, and Sperenberg over 3900 feet (here sodium chloride only). Below the Zechstein are copper-bearing black shales or a series of red continental deposits (Rotliegende), and the Permian here, as in Russia, is terminated by other red beds.

Plate 32. — Late Lower Permian paleophysiography

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 24 (p. 355) for Pennsylvanian paleogeography.

The time of the seas shown on this map (the earlier invasions are in darker shading) is late Lower Permian, but the rising of the mountains came later. Eastern North America, in the Appalachian area, stood higher then than at any subsequent time. Note also the Ancestral Rocky Mountains of Colorado, and the several domal areas in the central United States (see pp. 367–369, 426). The medial ridge through the Canadian Shield is drawn too prominently, and the broken-lined area in California-Sonora means that epeiric seas may also have extended here.

The climate was warm arid, and the seas of the Great Plains area left much salt and gypsum in their withdrawal (pp. 423–424). The Permian ice age came just after the time of this map and probably before the Appalachian Mountains had been completed (pp. 428–430).

The Great Mountain Making of Permian Time

Appalachian Revolution. — Earlier in this chapter it was stated that, with the exception of the southwestern states, the seas began to vanish toward the close of the Pennsylvanian, and that in late Lower Permian time the continent had again nearly all emerged from the sea. Then for a long time there is no record other than that of continental erosion. During the Paleozoic era previous to the Pennsylvanian, the continent had been four times in the throes of mountain making. None of these deformations, however, had the significance of a revolution (see p. 91). Each one of these crustal movements, in turn, folded some area of greater Appalachis and finally also Llanoris of Louisiana and Texas. Then came in

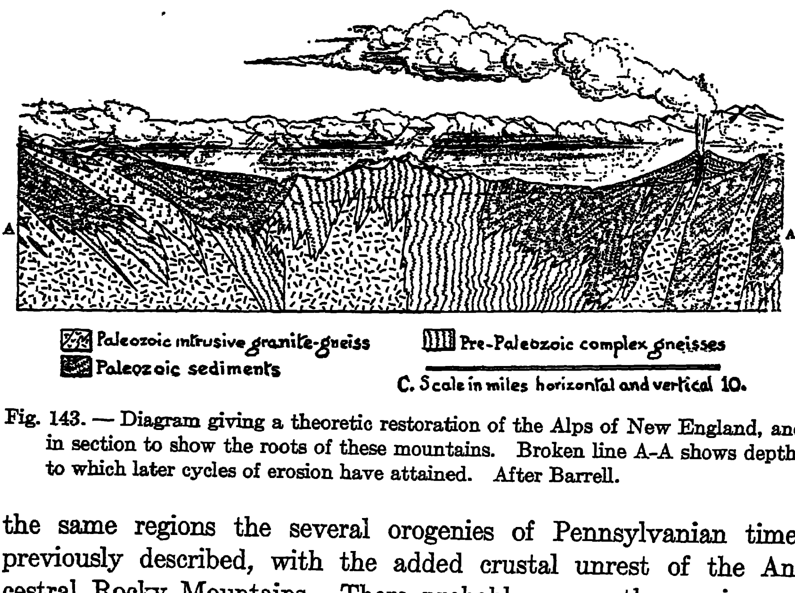


Fig. 143. — Diagram giving a theoretic restoration of the Alps of New England, and in section to show the roots of these mountains. Broken line A-A shows depths to which later cycles of erosion have attained. After Barrell.

the same regions the several orogenies of Pennsylvanian time, previously described, with the added crustal unrest of the Ancestral Rocky Mountains. There probably were other regions of movement along the Pacific border, in California and in the Washington-Vancouver area (see Figs., pp. 352 and 368). Volcanoes were then active from California to Alaska.

Early in Permian times all of these areas again appear to have been in motion, especially the whole of the Appalachian and Llanorian regions. With these uplifts the epeiric seas of early Permian time all vanished from the continent. The northeastern half of the Appalachian Mountains was then most decidedly in motion, the heretofore open folds being closed and finally overturned and overthrust to the northwest on a scale greater than anywhere else

in North America at this time. This has made the geology of the New England States and of the Maritime Provinces of Canada the most difficult of any to understand (see Figs., pp. 425, 426). The extent of deformation was also greater than at any other time, since the Appalachians extend from beyond Newfoundland to southern Alabama — a distance of over 2000 miles — while other mountains continue for 1200 miles southwestward across Texas, Chihuahua, and Sonora. At the same time, all of the domes and axes of the eastern United States were accentuated. Finally, North America was completely emergent and greater than it is now.

The Appalachian Revolution, beginning in Pennsylvanian and culminating in Permian time, was one of the most critical periods for the organic world in the earth's history, and may have been the greatest of them all with respect to changing environments. A glacial climate even came over the world in late Lower Permian time (see Figs., pp. 428 and 431).

How high the Appalachians stood in Permian time is hard to ascertain, but on the basis of the folds measured in Pennsylvania, it has been suggested that they may have been 5 miles high. However, as mountains rise slowly and their highest peaks are rapidly worn down during the time of their rising, it is probable that the Appalachians at no time had the grandeur of the present Himalayas. There may nevertheless have been peaks that stood from 2 to 3 miles high in Middle Permian time. (See Fig., p. 426.)

Permian Mountains of Eurasia. — The crustal instability of Europe during Pennsylvanian (see p. 351) and Permian times appears to have been as marked as that of North America. The Hercynian Alps of central Europe were reëlevated during earlier Permian time and toward the close of the period the Urals of Russia were rising. From northern India east to China, mountains had also arisen in late Pennsylvanian times.

Wadia in his valuable *Geology of India* states that to the north of peninsular India, following the Middle Carboniferous, there was a time of great earth movement, profoundly altering the face of Asia. These movements brought in a vast extension of the Tethyian mediterranean, originating a new geosyncline that extended over the whole of North India, Tibet and far into China. "The southern shores of this great sea . . . coincided with what is now the central chain of snow-peaks of the Himalayas, beyond which it never transgressed;" but, to the east and west of the Himalayan chain, great bays were extended to the south of this line into Upper Burma and Baluchistan, and toward the Salt Range. In consequence there is almost everywhere in India a great break in the geologic record, represented by an unconformity at the base of the Permian system.

From these deformations we learn that the closing period of the Paleozoic was a time the world over of crustal movements. The many red areas of America, Europe, and Africa attest widespread arid climates, and the tillites of many continents indicate that the temperature of late Lower Permian time was low.

Glacial Climate near the Close of Lower Permian Time

For nearly fifty years geologists have been describing unmistakable glacial deposits of Permian age in the continents of the southern hemisphere, but it is only during the present century

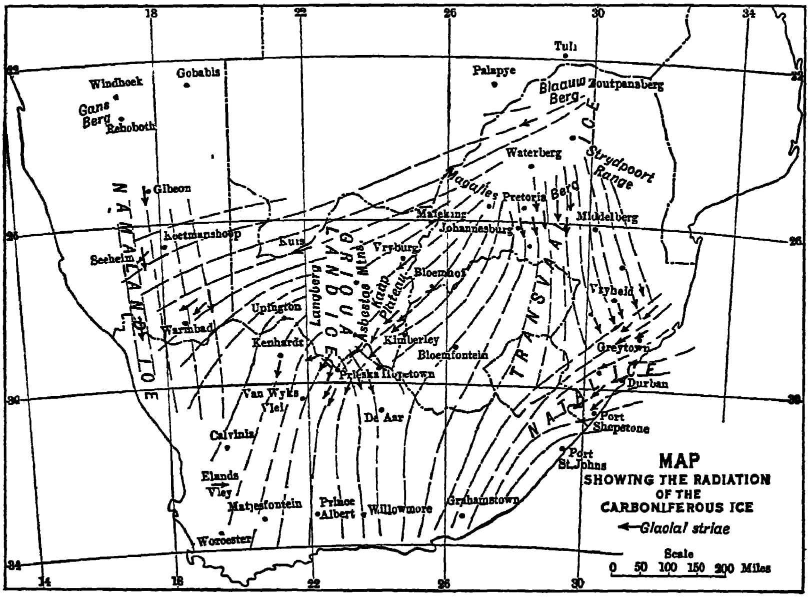


Fig. 144. — Map of the Permian glaciation of South Africa, as generalized by Du Toit. Also see map on page 431.

that their results have been widely accepted. It is now known that glacial deposits — bowlder clays called tillites — are of wide distribution.

South Africa has the best known Permian tillites, and here Du Toit in 1921 has brought together the evidence. All of Africa and Madagascar south of 22° and 23° respectively was covered by ice sheets that at their maximum were between 4000 and 5000 feet thick. Of snow-accumulating centers there were two major and two minor ones, which, coalescing, moved toward the southwest and south out into the oceans. The high land was in the north and

especially northeast, rising here to about 4000 feet above sea-level. The Transvaal ice sheet was the most extensive, moving at least 700 miles to the southwest. The tillites of the Dwyka series are in the northeast less than 100 feet thick, but in the south attain to 1500 feet, and in southern Karoo to 2000 feet (see Fig., p. 428).

Eight or nine horizons of glacial rock débris derived from floating icebergs occur in *South Australia* above the Coal Measures, some of them 200 feet thick, interbedded in 2000 feet of marine strata, and in *India* the very thick glacial deposits (Talchir) preceded the Permian submergence. The old polished, striated, and grooved ground over which the glaciers moved is known in India, Africa, and Australia. In *North America*, tillites seemingly of Permian age are known about Boston, Massachusetts, and striated stones have been reported on Prince Edward Island; Cairnes (1914) and Kirk (1919) also report tillites in different places in Alaska, and the latter thinks that some may be associated with the Weber quartzite of Utah and elsewhere. In England and Germany they occur at the base of the Permian. For the complete distribution of these glacial deposits, see Fig., p. 431.

The Permian glacial formations occur mainly on either side of the equator from about 20° to 35° north and south latitudes, but evidence of this kind is scattering above 35° in north temperate lands. On the other hand, the climate of that time was arid in the United States and in northern Europe, as is proved not only by the red beds, but even more by the great accumulations of gypsum and salt.

The evidence is now unmistakable that early in Permian times, and seemingly toward the close of the Lower Permian, most of the lands of the southern hemisphere were under the influence of a glacial climate as severe as the polar one of recent times, and that, like the latter, the Permian one also had warmer interglacial periods, for coal beds occur associated with the glacial deposits in Australia, South Africa, and Brazil.

Cause of Permian Glaciation. — What brought about this great change in the climate of Permian time, and why it was, apparently, mainly restricted to the southern hemisphere are as yet unsolved problems. Most geologists look for the explanation in the great derangements of the air and oceanic currents brought about by the marked crustal unrest during Pennsylvanian and Permian times, shown in the mighty mountain chains risen in the several continents at this time (Figs., pp. 352 and 368). Another factor that may have had much to do with the bringing on of this glacial climate was en-

larged Antarctis, which seemingly then united with Australia on the one side and on the other with South America. Naturally, such upheavals and land connections must have also altered the oceanic currents.

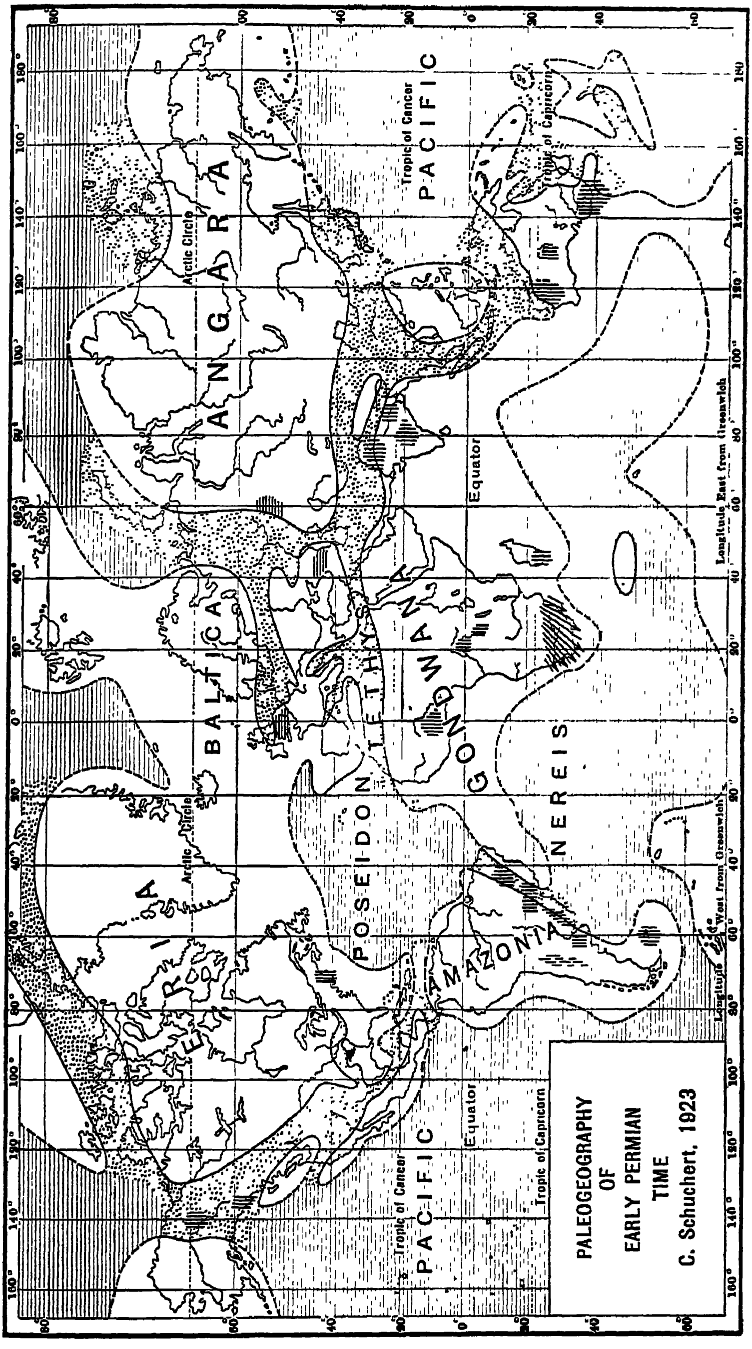
Gondwana and Tethys

Gondwana, the Great Southern Transverse Continent. — Something about this continent has been stated in Chapter V, and now further proof of its existence must be given. Such evidence relates mainly to wide-spread deposits of Permian age having the *Gangamopteris flora* (Fig., p. 432). This flora occurs throughout the southern hemisphere, and paleobotanists hold that it could have been so widely distributed only across a continuous land (see Fig., p. 431). Belief in the existence of Gondwana is wide-spread among European geologists, but some American workers do not yet believe in it, mainly because they hold strongly to the theory of the permanence of the oceanic basins and continents. Without this continent, on the other hand, paleontologists cannot explain the known distribution of Permian land life, and, further, its presence is equally necessary for the interpretation of the peculiar distribution of marine faunas beginning certainly with the Devonian and ending in the Jurassic.

Tethys, the Greater Mediterranean. — To the north of Gondwana lay the great medial ocean which Suess has named *Tethys*, after the consort of Oceanus (see Fig., p. 431). The present Mediterranean is a remnant of this once grand middle ocean which widely overlapped northern Africa, southern Europe, and Asia, and long extended unbroken from France and Spain into the eastern Indian and Pacific oceans, from time to time connecting with the Arctic Ocean by way of the Ural geosyncline. How often it was in open connection with the Atlantic is not yet clear, but that it had such communication is seen in the similarity of certain southern European and Gulf States faunas (Helderbergian, Kinderhookian, and Comanchian).

Life of the Permian

Marine Life. — In southwestern Texas the thick deposits of early Permian time abound in a varied marine life, part of which also spread widely over Arizona and Nevada. The faunas are no longer cosmopolitan like those of the Pennsylvanian. In many ways, they are the Pennsylvanian life changed into other local species, and this is especially true of the Protozoa (fusulinids), brachiopods, gastropods, and bivalves. The productids are still common, while



145.—Paleogeography and areas of known glaciation of early Permian time. Oceans are ruled, epeiric seas dotted, and places of glaciation lined (vertical lines, areas of proved glaciation; horizontal lines, of uncertain glaciation). Note the transverse shape and connected condition of the continents of this time.

the trilobites are almost gone. The heralders of a later time are the actively swimming and widely dispersed goniatids and ammonids, which are now rapidly evolving into new genera and hence are the fossils by which the marine formations may be correlated from country to country. In subsequent chapters we shall see how these "Ammon's horns" abound in the Mesozoic seas.

Final Permian Marine Faunas. — The last stand of the Paleozoic marine life was in extensive Tethys, the greater mediterranean, whose rock and organic records are found in the eastern Alps and the lands to the east as far as the Himalayas. In these warm waters of late Permian times the descendants of the Upper Carboniferous corals, brachiopods, and molluscs still swarmed in varied profusion well into late Permian time. When the record of the marine Triassic begins, however, it shows that a great change has taken place, for now all the Paleozoic fusulinids, corals, blastids, productids, and trilobites are gone, and there is a new assemblage of more modern molluscs, echinids, and hexacorals, the essential denizens of the medieval marine world. The change began in the vanishing seas of the late Permian, and when the oceanic waters returned to the continent, especially in Tethys, there was a world of new and small forms that soon deployed into the diversified Triassic faunas.

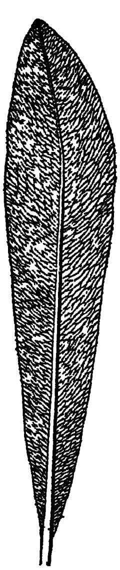


Fig. 146. — Leaf of the Permian net-veined Cycadophyte *Glossopteris* (*G. indica*). From Credner's *Elemente der Geologie.*

Cool Climate Cosmopolitan Flora of the Southern Hemisphere. — In the southern hemisphere, due in all probability to the cool climate brought about by the glacial period of late Lower Permian time, the more characteristic elements of the older cosmopolitan flora were in part wiped out and some of the elements which remained were evolved into new forms that soon took possession of the ancient land Gondwana (see p. 431), and finally of the entire southern hemisphere, including Antarctis. This plant assemblage is known as the *Glossopteris* or *Gangamopteris flora*, because of the prominence in it of these two plants (see Fig., above). The flora was less striking, both in size and variety, than its predecessors, and less luxuriant, but was hardier and had thicker and less ornate leaves. It appeared at about the same time in Africa, Australia, Tasmania, southern India, and South America

The paleobotanist Berry tells us that *Glossopteris* and *Gangamopteris* were simple fern-like fronds, shaped like those of the common hart's-tongue (*Scolopendrium*), and were borne on creeping stems or rhizomes (*Vertebraria*). It appears that *Glossopteris* is seed-bearing (the seeds are called *Nummulospermum* and *Samaropsis*) and is a Cycadophyte.

In this Glossopteris flora were relatives of the calamites of the Pennsylvanian, other Cycadophytes, many ferns, conifers (*Voltzia*), and probable relatives of the northern cordaites. With the amelioration of the climate in Middle Permian time, various members of the northern and older flora succeeded in reëstablishing themselves, among them *Lepidodendron* and *Sigillaria*; these were the Lepidophytes. The tree-fern *Psaronius* also re-appears. The ringed woods of earlier colder climates are significantly absent in later Permian floras.

The Glossopteris flora began to spread as early as, or even earlier than, Middle Permian time into the northern hemisphere, for it is known in northern Russia to the west of the Urals, and to the east of them in the Altai Mountains and elsewhere in Siberia. Finally, parts of it survived into Mesozoic time.

Permian Insects. — Near Elmo, Kansas, E. H. Sellards some years ago discovered in early Permian deposits insect remains that he, and later C. O. Dunbar, have collected by the thousands. These are greatly changed from those of the Pennsylvanian, since the may-flies, large dragon-flies, and many small forms transitional to the higher orders are now the leading stocks. Some Palæodictyoptera are still present, but cockroaches are rare. Another insect locality, but of late Permian time, has been found in Australia, and here occurs the oldest known beetle (Coleoptera). The Permian insects of Kansas are now being studied by R. J. Tillyard of New Zealand.

During the Lower Permian a great change took place among the insects, for they became not only smaller but more like modern forms. This modernization grew more and more marked in later Permian time, as is attested by the Australian forms. Judging from the insects of Triassic times, we see that those of the later Permian must have introduced complete "metamorphosis" (a transformation, as maggot to fly or caterpillar to butterfly) in their growth from the egg to the adult, and also resting stages because of winters or seasons of drought and absence of food, as is done by modern forms. This fundamental change is attributed to the general aridity so prevalent throughout the Permian and Triassic, rather than to cold winters.

Some of the early Permian insects are still very large, indicating that the climate remained warm, and this conclusion is supported by the abundance and variety of reptiles of about the same time entombed in northern Texas. This was, however, before the glacial climate appeared.

Land Reptiles of the Permian. — In most places where red beds begin to appear in the strata of later Pennsylvanian time, and especially in the earlier Permian, reptilian bones are apt to occur. Nowhere, however, are complete skeletons found except in eastern New Mexico, central Oklahoma, and more especially in northern Texas. More than forty genera are now known and several museums, particularly that of the University of Chicago, show these reptiles in all of their skeletal perfection.

In the Wichita region of Texas, Williston has discovered two graveyards replete with entire skeletons, some of which are 4 feet long, resting in a natural position and piled upon one another to a depth of 2 feet. The creatures had probably died quietly in a stagnant pool of water that dried out annually, causing successive generations of the reptiles to be heaped one upon the other in layers. Even today in the same region there are small perennial rivers in wide valleys, and here and there in the permanent pools live fishes, such as catfish and carp, along with frogs and mud-puppies. The modern occurrences suggest the probable conditions under which the late Paleozoic amphibians and reptiles existed.

The evolution of the air-breathing vertebrate life of the Pennsylvanian and Permian, Williston says, is the most important phase of the whole progress of evolution, for at the close of the Permian we find forms foreshadowing the chief groups of the higher vertebrates of modern times. The predominant types of the Pennsylvanian were the armored Amphibia, known as the stegocephalians. More is said of these in Chapters XXVII and XXX. It is among the microsaurs that we find a distinct advance toward a higher existence away from the water, and in the direction of the reptiles. Some lost the dermal armor completely and became fleet of movement, best seen in the structure of the limbs, which mimic so closely in form and structure those of the modern quick-running lizards as to be practically indistinguishable. We may be assured that some of them before the close of the Pennsylvanian were inhabitants of high and dry lands where fleetness of movement, rather than obscurity in coloration and habitat, preserved them from their enemies, and that they were crawling reptiles in everything save in some technically significant details of their palates. Specialization of the microsaurs

had reached the extraordinary extent of snake-like, limbless forms by Middle Pennsylvanian time.

In addition to these two types of amphibia we have two others: the temnospondylous type, in which the vertebræ are divided into separate elements, and from which the mammals eventually arose; and the stereospondylous type, which terminated in the gigantic labyrinthodonts of the Upper Triassic. (Williston.)

Of Permian vertebrates, by far the richest and most varied fauna known is that of America, especially of Texas and Oklahoma. It was an independent and isolated development that had no intercommunication with the reptiles of other continents until well into Triassic time. The faunistic evolution here produced striking results, but does not seem to have been the direct line into the higher and more modern vertebrate stocks. Seemingly this ascending evolution took place in Africa.

At least three very distinct phyla of reptiles and as many of amphibia are known. Among the reptiles occur the *pelycosaurs* (*Naosaurus*, *Dimetrodon*), derivatives of a prior type which had branched off before the close of the Pennsylvanian; the true *cotylosaurs* (*Diadectes*), with, in some cases, singular developments of dermal carapace, or armor, strongly suggestive of the turtles and unknown elsewhere; and a third type (*Labidosaurus*, *Pariotichus*) of small crawling reptiles with large head, short tail, and short limbs, whose nearest, but remote, relatives are found among the pareiasaurs of South Africa. (Williston.)

Salt Deposition

Occurrence. — Rock salt and gypsum may have accumulated in the sedimentary strata at any time and place when the necessary physical conditions, discussed on pages 84 to 89 of Pt. I, were present. In America extensive salt-depositing basins came into existence toward the close of the Silurian (Salina formation) in New York, Ohio, and Ontario (Pl., p. 273, Map 4). The salt brines of western West Virginia, on the other hand, rise from rocks of Upper Devonian age and those of southeastern West Virginia are of early Mississippian time, while in southern Louisiana occurs rock salt of Cenozoic age. The most interesting and by far the thickest beds, however, occur in Germany near Berlin (Sperenberg, 3000 feet of marine salt), and at Stassfurt in southern Saxony, where there is an average thickness of 3000 feet of salts. These deposits are of Middle and Upper Permian time. At Stassfurt occur more than thirty saline minerals, and it is estimated that the salts here were accumulated in less than 10,000 years, a calculation based on the many annual layers which are clearly demarcated. (Also see p. 424.)

Theory of Salt Formation. — Beds of rock salt, in a section, may be separated from one another by clay, limestone, or dolomite or there may be a single bed of very variable thickness and made up of many kinds of salts.

Ocean water contains, on the average, about 3.5 per cent of solid matter in solution, most of which is sodium chloride or rock salt (78 per cent of the sea salts), and it contains also calcium sulphate or gypsum (about 3.5 per cent) (see Pt. I, p. 91). The two compounds are commonly associated with each other, but not invariably, for gypsum is sometimes derived from other sources, and rock salt may be dissolved and washed away from a given locality, leaving the gypsum. Still, concentration of the oceanic salt water is the principal source of these deposits. In general, the following is the order of deposition: (1) precipitates of lime carbonate and some hydrous iron oxide; (2) most of the gypsum, which precipitates when 37 per cent of the sea water is evaporated; (3) mixtures of gypsum and common salt; (4) pure sodium chloride, when 93 per cent of the original water is gone; (5) in exceptional conditions, mixtures of sodium chloride with salts containing magnesium, potash, bromine, and iodine. This order, however, is subject to seasonal alterations, variations in temperature, and other conditions, so that alternations of gypsum, salt, and clay are exceedingly common in saline deposits.

It is probable that all of the more extensive accumulations of sodium chloride and calcium sulphate are connected with marine sedimentation, under dry, warm, or cool to even cold climates, in very shallow seas or bays more or less shut off from the oceans by land bars or barriers and previously described as detached salt lakes (p. 86 of Pt. I). The essential conditions are (1) a dry climate constantly taking away by evaporation some of the water in (2) nearly land-locked seas, and (3) the supplying of the loss at frequent intervals (high tides) from the oceans. These waters must, therefore, be practically free of circulation, at least with no greater flow than that produced by the tides at the heads of bays.

Absence of Fossils in Salt Beds. — In basins supersaturated with salts one naturally would not expect much life, and when the saturation is marked (15 to 22 per cent) they are practically "dead seas." Even where the saturation is but a little above that of the ocean, animal life becomes scarcer and the molluscs make thicker and rougher shells. The Salina and Permian seas in the places of salt accumulation left no fossil record.

The importance of sodium chloride to humanity is at once seen

in the statement that the amount of this salt sold annually in the United States is about 130 pounds per person, while of sugar the per capita consumption is 108 pounds. In 1918, the United States produced of sodium chloride 7,239,000 short tons, and the amount used in the arts and on the table was 7,142,250 tons, worth about $26,670,000.

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CHAPTER XXXII

CLIMATES OF THE GEOLOGIC PAST, AND THE "CRITICAL TIMES"

PART I. CLIMATES, PRESENT AND PAST

Geologists have long been deeply interested in the climates of the past, not only because of their stimulating or depressing effect on the organic world, but also on account of their different effects on the materials that go into the making of the sedimentary rocks. Climate is not merely a matter of temperature, and of quantity or intensity of sunshine, but equally one of atmospheric composition. In it moisture and carbon dioxide play great rôles. Plants are dependent upon both, and animals feed upon plants. Organisms live, as a rule, wholly in the light of the sun on the dry lands and in the shallow waters and only rarely in utter darkness. When, therefore, Nature changes any of these regions, locally or widely, the organic world is forced to adapt itself or perish in the attempt. Ceaselessly the cycles unfold themselves, and all Nature is interlocked.

The Atmosphere: a Thermal Blanket. — LeConte has well said that the atmosphere is a kind of blanket put about the earth to keep it warm. So far as life is concerned, this is one of the most important functions it has, though its importance is great in other directions also. The reason for this is that the air is transparent to those rapid vibrations received from the sun which we know as light. On reaching the ground, however, a considerable portion of the light is transformed into much slower vibrations, which we perceive as heat. Now if there were no atmosphere, these heat vibrations would pass off into space and be lost; the result would be that the burning heat of the unmodified sunlight would be turned into almost the intense cold of outer space at night. This is prevented by the atmosphere, which retains the heat and thus moderates and equalizes the temperature on the surface of the earth. Of the various gases which compose the atmosphere (see p. 9 of Pt. I), the oxygen and nitrogen are transparent to both the quick light vibrations and the slower heat ones; they could not therefore alone modify temperature in any great degree. The carbonic acid gas and especially the water vapor in the air, on the other hand, while transparent to light, are

more nearly opaque to heat vibrations, and it is due to them that the heat is retained. The larger proportion there is of them in the air, therefore, the more equable will be the temperature. This explains why deserts, with their dry atmosphere, suffer such changes of temperature between day and night, while the moist atmosphere of oceanic islands gives them such even climates.

Water vapor in the last analysis is derived entirely from the oceans through the energy of the sunlight. It rises into the atmosphere and the winds blow it over the lands, upon which it falls as dew, rain, snow, and hail. In the United States the annual rainfall varies between 5 and 100 inches.

It must not be understood that all sunlight is thus turned into heat, as a portion is absorbed in passing into the atmosphere and another part is reflected back as light and not transformed; it is the remaining portion that is thus effective.

Elements of Modern Climates. — Climate in relation to life is the most important factor in the organic environment. This is readily seen in that climate may be dry and hot, or very cold, and in such places life is scant; or it may be wet, hot or cool, equable or variable, and under such conditions productive of much life. The word climate has to do with the average of a complex that makes up the atmospheric conditions of a region, while weather is based on the variations of temperature, pressure, wind, clouds, and rain from day to day. The study of present climates is called *climatology*, and that of the past *paleoclimatology*.

If the earth had a smooth surface devoid of an atmosphere, the distribution of the heat received from the sun would be purely a question of latitude, and there would be a regular gradation of solar climates from the hottest at the equator to the coldest at the poles, due to the inclination of the sun's rays to the earth's surface being most direct at the equator and with the greatest slant at the poles. All of this is, however, profoundly modified in the presence of (1) a variable atmosphere, (2) a high or low relief of the earth's surface, (3) winds, and (4) oceanic circulation. Nevertheless it remains true that latitude is the most important single factor controlling climate with respect to temperature. On the other hand, the effect of altitude upon temperature is analogous to that of latitude, and is seen in the prevalence of cool climates at high levels near the equator as contrasted with the mild ones of many places near sea-level in the temperate zones.

A climate is said to be *marine* when the winds blow directly from the oceans over adjacent lands, making them more or less mild and

equable, as in the seaboard countries of western Europe, and *continental* when the winds are not from the oceans, as in the interior of North America and Asia.

The wetness or dryness of a climate is determined especially by the prevailing movement of moisture-bearing winds and the relief of the land, while a second and important control is the location of a region with respect to storm tracks. The rainiest regions of the world are found on the windward slopes of mountain ranges not far from the ocean, where the moist winds, forced by the mountains to ascend rapidly, cool because of this rising and expansion, and shed their moisture (= orographic rainfall). To the leeward of such mountains, arid conditions generally prevail. Along tracks of cy-

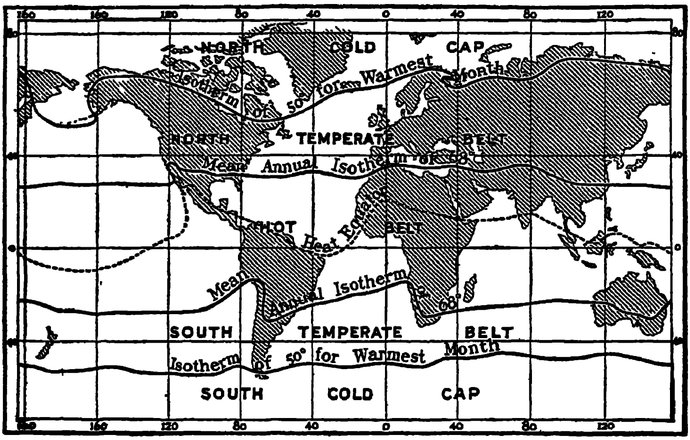

Fig. 147. — Zones of temperature as defined by Supan. Lines of equal temperature are called isotherms. From Ward's *Climate.*

clonic storms the climates have copious rainfall (cyclonic rainfall), as in the eastern United States.

In a general way, the earth's surface is divided into five climatic zones, the equatorial torrid belt, the two temperate zones, and the two polar zones. These zones, however, are not strictly defined by latitude but by lines of equal temperature, or *isotherms,* as illustrated in the above figure.

Criteria for Determining Geologic Climates

Tills and Tillites. — The tills are the morainic deposits and bowlder clays of glaciers, and the work done by these streams of ice is described in Chapter V of the first part of this text-book. The geologic deposits made by ice and ice water during the Great Ice Age (Pleis-

tocene) are called tills, while the older and consolidated ones are known as tillites. These formations, when of coarse fragments (morainic), consist of unassorted and heterogeneous rock materials, and the pieces are of all sizes from flakes of mud to blocks sometimes tens of feet in length. This heterogeneity is due to the lack of sorting power in moving ice. On the other hand, the water-laid sandy clays (pellodites) are usually seasonally banded with lighter (summer) and darker (winter) materials, the particles being angular, with granular feldspar, calcite, and other easily dissolvable minerals present. These are the varved clays, each pair of bands making a *varve*.

In the tillites we have the best of evidence to prove, at least locally, the existence of cold climates like those of the high Alps or those of polar lands. Many of the known tillites are of local occurrence, but some are indicative of world-wide glacial climates.

The existence of intermediate warmer times during the ice ages may be ascertained from the nature of the deposits, but more surely from the entombed animals, since they are of temperate climates; added evidence lies in the presence of carbonaceous strata or even coal beds and an abundant flora.

Wind-blown Sands. — In water-laid sandstones the quartz particles are nearly always angular and well assorted, but in dune and desert sands the grains are more or less well rounded, smooth and frosted, minutely pitted through impact, and usually well assorted as to size. Therefore well rounded sands with frosted surfaces are apt to be indicative of desert climates. They may accumulate as continental eolian deposits, or be blown into river or marine strata. When, in addition, eolian sandstones are strikingly cross-bedded, with the bedding planes more or less long and concave, the evidence is decidedly in favor of desert dune accumulation (see Fig., p. 470). A sandstone with some rounded grains, or even one largely made up of such, may nevertheless be of fresh-water or marine deposition, the material then being derived from older eolian sandstones. It is now well known that sand may pass through several cycles of deposition, and as an example may be cited the eolian but marine-laid St. Peter sandstone of Middle Champlainian time, which came largely if not entirely from the Cambrian sandstones of wind-blown origin deposited in the Croixian seas. For a complete discussion of the nature and environmental significance of sandstones, see Sherzer, 1910.

Feldspar. — Ever since the Silurian, in wet and warm climates there has been an abundance of vegetation, resulting in large amounts of humic acids that dissolve out of the weathering rocks most of

their soluble minerals. On the other hand, in dry and cold climates there is little or no vegetation, and besides, nearly all of the rocks are fragmented through marked fluctuations in the temperature. Therefore in the continental deposits, or even in the marine strata adjacent to cold or dry lands, the formations have more or less of fragmented feldspar and calcite or rarely limestone and dolomite. Therefore formations more or less rich in these detritals are indicative of cold or dry climates.

Sediments as Climatic Indicators. — Johannes Walther in the third part of his *Einleitung* — *Lithogenesis der Gegenwart*, 1894 — was the first to emphasize the fact that the sedimentary formations of the ancient seas, and more especially the continental deposits, have within themselves a climatic record. His book entitled *Das Gesetz der Wüstenbildung*, 1912, is a classic on the nature of deserts and their deposits. He points out that the deserts of central Asia are red in color, that carmine-red dunes are wandering across Arabia, while yellows are of wide distribution in Trans-Caspia and in Africa. The dust of the Sahara falls in Italy as the "blood rain." In temperate moist regions, the soils are chiefly gray, yellow, or brown in color, while in tropical ones they are red and the laterites are brown-red. In America Barrell wrote much on the same subject between 1907 and 1919, and Blackwelder is another student of sediments and climates.

It is now evident that the color, character, and chemical nature of the geologic formations are largely connected with climate. Thus, a sedimentary layer which is deposited under water and in contact with much decaying organic matter, will necessarily be kept in a reduced or unoxygenated condition, whereas if it comes to rest on an exposed dry surface where aërated waters circulate down through it, the materials are likely to become thoroughly oxidized. Alternations in color from red deposits to gray and white sandstones and conglomerates, with coal beds such as occur in the American Carboniferous succession, appear to indicate wide swings of climatic change from warmth and semiaridity to cooled, humid, and probably even cold climates. Accumulations of *salts* and bedded *gypsums* in red formations are indicators of dry climates. *Loess* and steppe deposits, the residuals of cleavable, soluble, or decomposable minerals, plus finer abrasion products, are dust accumulations blown out of deserts or cold dry regions into grass-covered areas where these clays are retained by the moisture and vegetation. Widespread and thick formations of *limestones*, *dolomites*, and *oölites* are laid down in shallow warm-water seas

and hence indicate equable and mild climates on the adjacent lands. Widely spread *coal beds* are the accumulations of swamps that probably are more often of warm moist climates than of cold ones. Finally, all mud-stones that are tension- or " sun-cracked " are evidence of seasonal exposing and the drying out of the contained water by the atmosphere. This phenomenon is particularly common in the oxidized red formations that were laid down under more or less arid climates. In such, rain-pitting is also common.

Through an understanding of the present operations of the laws of nature, we learn how to discern their effects throughout the geologic ages, and to see that the rocks, like the living organisms, have within themselves the records of their climatic environments.

Fossils as Life Thermometers. — Paleontologists have long been aware that variations in the climates of the past are indicated by the fossils, and Neumayr in 1883 brought the evidence together in his study of climatic zones. Since the distribution of living plants and animals is so largely controlled by temperature, it is but natural that fossils of the ancient organic worlds should also indicate temperature ranges and something of their environments as well. Some of this evidence has more recently been briefly restated by Schuchert and Matthew.

Fossil plants have long been used to decipher climates of the past and great dependence is placed upon them by the paleontologists. When fossil tree-ferns, cycads, palms, magnolias, and breadfruit trees are found in continental deposits in high latitudes, the conclusion that the land had a warm climate when they lived there is sound. In the same way, when the ancient marine deposits of arctic countries have an abundance of fossil corals, or better, coral reefs, shelled cephalopods, and reptiles, the conclusion follows that these seas also were warm.

Whole groups of invertebrate animals are conditioned by warm waters and such are now used extensively to work out the climates of the past. The colonial large-shelled foraminifers (Fusulinidæ, Nummulinidæ); an abundance of stony corals and especially the reef-builders; reef-making bivalves (rudistids, oysters); a highly varied bivalve and gastropod fauna, and especially with large or highly ornate forms; and an abundance of shelled cephalopods (nautilids and ammonids) are all indicators of warm waters.

In continental deposits the presence of amphibians, reptilians, many kinds of mammals, and especially large ones and primates, are also indicative of warm land climates.

Climates of Geologic Time

Rise of Paleoclimatology. — In the first half of the nineteenth century, nearly all geologists believed that the origin of the earth took place according to the theory of Laplace. This postulates the origin of the earth out of the sun as a hot gaseous star that in the course of cosmic time gradually cooled, passing through a fluid stage into a more solid one with a rock crust; then during the long geologic ages, as the crust became thicker, the climate cooled down from a very hot one to the present zonal arrangement from tropical warmth to polar ice-caps. The idea that the earth had very recently passed through a much colder climate than the present one came into general acceptance only during the last half of the nineteenth century.

The evidence in many lands is overwhelming that the earth is only now emerging out of the glacial climate of Pleistocene time. The recognition of this fact began in the Alps, that wonderland of mountains and of extraordinary expanses of creeping ice. It was an Alpine chamois-hunter, Perraudin, who in 1815 directed the attention of the engineer De Charpentier to what is now so widely accepted, namely, that the large bowlders perched on the sides of the Alpine valleys were carried there and left by the present glaciers when they were thicker and greater in area. For a long time this conclusion was thought extravagant, but eventually Perraudin persuaded another engineer, Venetz, of its correctness. The latter told the Swiss naturalists at their meeting at St. Bernard in 1821 that his observations led him to believe that the whole Valais had been formerly covered by an immense glacier and that this glacier extended even outside of the canton, covering all the Canton de Vaud, as far as the Jura Mountains, carrying the bowlders and loose materials which are now scattered as " erratics " all over the large Swiss valley. Further, that the accumulation of heterogeneous rocks into moraines was the work of retreating glaciers, and that the time of their origin " is lost in the night of time." It was these conclusions republished in 1835 by De Charpentier that led Louis Agassiz in 1836 to take up a study of the glaciers of the Alps and in the following year to become the greatest advocate of the Ice Age. Agassiz's *Études sur les Glaciers*, 1840, and De Charpentier's *Essai sur les Glaciers*, 1841, are the classics that have revolutionized all thought about the climates of the past.

Succession of Geologic Climates. — Many older tillites are known, in fact, every year new ones are being discerned. Geolo-

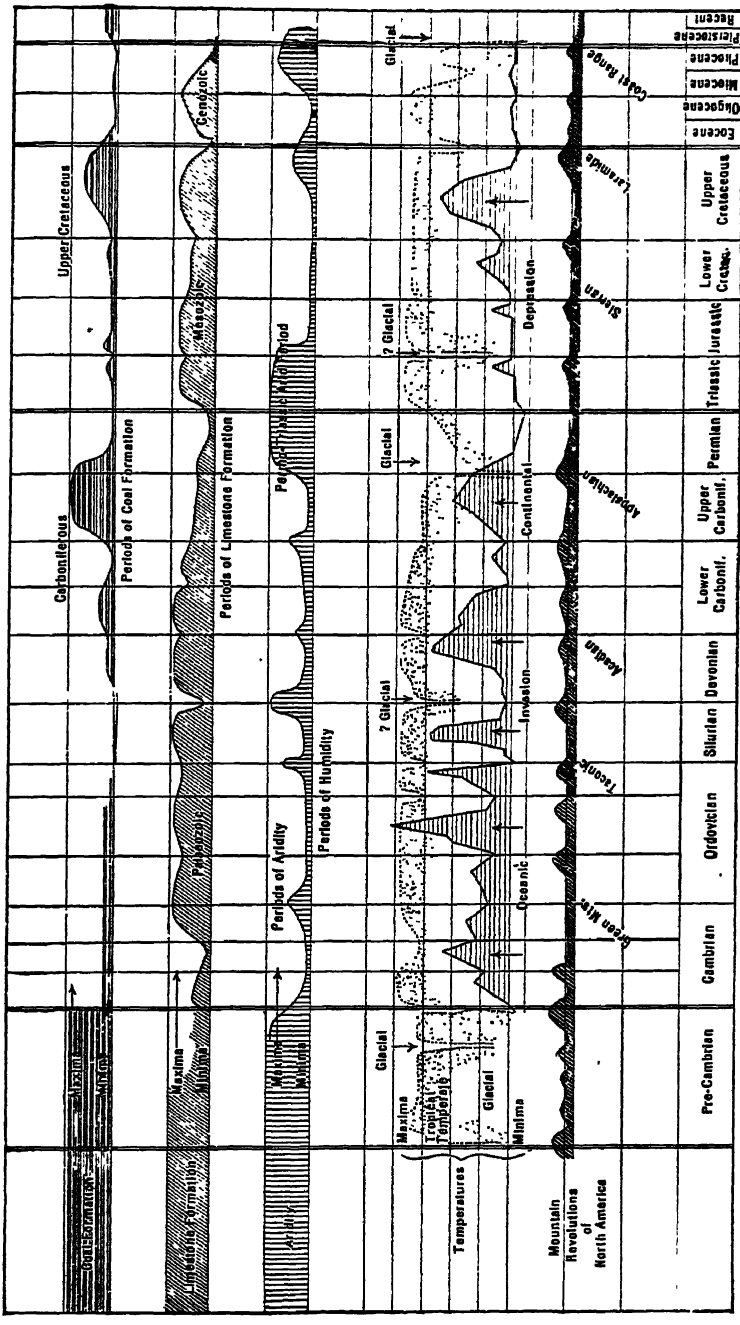

Fig. 148. — Diagrammatic geologic vista of the earth's changing surface and atmosphere. Here the times of maximum coal, limestone, and mountain making are correlated with those of maximal variations in temperature, aridity, and oceanic spreading. After Schuchert, from Osborn's *Origin and Evolution of Life*, 1917.

gists now know of at least seven times of decided temperature changes: *early and late Proterozoic,* late Silurian, *early Permian,* late Triassic, late Cretaceous, and *Pleistocene;* and of these, four (those italicized) were greatly reduced or glacial climates.

The marine "life thermometer" indicates vast stretches of time of mild to warm and more or less equable temperatures, with but slight zonal differences between the equator and the poles. The great bulk of marine fossils are those of the shallow seas — areas that best simulate the climatic conditions of the lands — and the evolutionary changes recorded in these "medals of creation" are slight throughout vast lengths of time. These long periods of slightly varying climates are, however, punctuated by short but decisive intervals of cooled waters and consequent greater mortality, followed by quickened evolution and the rise of new stocks.

On the land the story of the climatic changes, as interpreted in the main from the entombed plants, is more variable and decided, but at times the equability of the temperature simulates that of the marine areas. In other words, the lands also had long-enduring life assemblages that indicate mild to warm and but slightly variable climates.

Periodic Marine Floodings. — Into the problem of land climates enter factors that are absent in the marine ones, and these have great influence upon the temperature and moisture of the continents. Most important of these is the periodic warm-water inundation of the continents by the oceans, causing climates that are milder and moister. With the vanishing of the floods, somewhat cooler and certainly drier conditions are produced. The effect of these periodic floods must not be underestimated, for the North American continent, as has been said, was variably submerged at least seventeen times, and over areas variable between 150,000 and 4,000,000 square miles.

Periodic Times of Mountain Making. — When to these factors is added the effect upon the climate caused by the periodic rising of mountain chains, many of which must have been snow-covered, or by the presence of explosive volcanoes clouding the earth's atmosphere and obscuring the sun by a thin blanket of ashes that helps to cool the atmosphere, it is at once apparent that although the climates were mild as a rule, they must have been slightly variable.

Conclusions. — In general, we may say that the temperature fluctuations seem to have been slight throughout vast stretches of time, but geologically the climates varied between mild to warm pluvial, and mild to cool arid or even to glacial ones. The arid

factor has also been of the greatest import to the organic world of the lands, blotting out whole floras and faunas and establishing impassible barriers to the migration of life. Further, during emergent periods the lands were apt to be connected by land bridges, and these barriers changed the oceanic currents and likewise the local climate (study Fig., p. 445).

PART II. CYCLES OF LIFE AND CRITICAL TIMES

We have seen that great areas of our own continent have been repeatedly inundated by marine waters, with the effect of extending the shallow-water areas of the oceans and thus giving rise both to expanding marine life — expanding not only numerically in individuals but also in species — and to restrictive evolution of the land life.

When the lands are low and more or less covered by seas, the areas so affected have climates of the insular type. Forests are then more prevalent and open meadows are restricted. With the removal of the seas, the lands become drier, and the forests diminish. If, in addition, great areas are elevated into mountains, the climate becomes cooled, with the alpine parts icy and cold; and if the mountains deflect the air current or take out their moisture, then on the leeward side of the highlands semiarid to desert regions result. A warm climate followed by a cold one is productive of many new species, most of the specialized ones dying out and others changing into new forms. With the lack of moisture, and the appearance of deserts, whole floras and faunas are almost wiped out, and those elements that remain are highly specialized through adaptation. Such changes bring on in the areas so affected *critical times* for the land life.

Many times during the geologic ages the lands were reduced to but little above sea-level, and at these times there were world-wide mild climates. Such can be demonstrated most easily for Pennsylvanian, Jurassic, Cretaceous, and Oligocene times. Contrast, then, this condition with that of the present topography, with its marked zonal climatic belts, high mountains with cool to cold climates, polar ice caps and hot equatorial climates, and one fifth of the land area so lacking in moisture as to be deserts. All of the present deep oceanic water has been icy cold since the glacial times of the Pleistocene, when all North America was covered by a thick ice-sheet down to the Ohio River, and Europe south to Poland. Then the extreme cold was at its greatest, walrus living as far south as Georgia and musk-oxen ranging from New Jersey southwest

through Kentucky into Oklahoma and Nebraska. Such great climatic changes appear rapidly in geologic time, and on the lands blot out many kinds of plants and animals.

Africa to-day, due to its equatorial situation and to a long emergent history, is peopled by peculiarly localized faunas, among which the most notable elements are the many kinds of mammals, not very unlike those of Pliocene time. Now think what destruction would befall this asylum, with its hundreds and even thousands of peculiar forms, if the greater part of the continent were to be covered by the oceans, or a very cold climate were to prevail. The last remainder of the Pliocene organic world would be gone. However, as no continent is ever wholly inundated by the marine transgressions, only parts of the floras and faunas would be killed off, while others would be modified to suit the changed conditions. If small asylums of dry land remained — and surely there would be such — when the waters retreated the floras and faunas of these asylums would expand with their enlarging habitats and their changing environment, and evolve into new life assemblages expressive of their time, but showing unmistakable linkage with those of the Pliocene. Physical changes of this character have many times taken place and have had a most telling effect on the land life ever since the Silurian. On the other hand, the extension of the marine shallow-water areas has given rise rather to the wide dispersal of these faunas than to marked expansive evolution. It is when the restriction occurs that many of the species are blotted out, because of the more and more congested conditions and the general disturbance of the web or balance of nature.

A survey of the organisms of the past reveals the vanishing of whole faunas from extensive countries, which were then repeopled by other forms from elsewhere. Countless groups, once flourishing, are no more; many others have had their day, and are now on the decline; many are now prospering, or even on the increase, and seem to have a future before them.

These facts of the geologic record long ago attracted the attention of naturalists and a century before our day the great Cuvier of France brought into almost universal acceptance the fallacious *cataclysmal theory*. According to this theory the succession of changed life assemblages was explained as due to wholesale destructions brought about by sudden geologic alterations that changed wide areas of sea into land or vice versa, followed by successive re-creations of plants and animals. Long before Cuvier, however, another Frenchman had thought of life as continuous and evolving

with change. This was the naturalist Buffon, and with him came the theory of continuity of conditions and life. This theory of *continuity* (uniformitarianism) was put into geologic form by James Hutton of Edinburgh and then developed into general acceptance by the geologist and text-book writer, Charles Lyell. With Lamarck of France and Charles Darwin of England came the revolution of thought from cataclysms and special creations to continuous development and organic evolution.

Small Heralders and their Giant Descendants. — It is one of the most striking generalizations of Paleontology that the upwelling of future organic rulers begins in unobtrusive small forms. In all stocks of plants and animals such potential rulers are always present. In fact, each individual, however large, begins in a microcosm, and life itself began in the smallest and simplest globules of primitive protoplasm. The shelled cephalopods begin in the Lower Cambrian with a length rarely exceeding 10 millimeters, and along various lines and at different times develop into giants many feet across. In the Silurian, the fishes are all diminutive, and even though great giants are present in the Devonian (Arthrodira), the biggest ones in many families come with the Mesozoic and Cenozoic. The Amphibia are rarely 3 feet long in the early Pennsylvanian, but giants two to four times as large come in the Permian and more especially the Triassic; the reptiles repeat the development of the Amphibia but swing rapidly through the Permian to become in the Mesozoic time the rulers of the land, the oceans, and the air. The titan dinosaurs of the Jurassic and Cretaceous are the most ponderous land animals that ever lived, ranging up to 40 tons in weight, and at least one of the " dragons " of the late Cretaceous attains a wing expanse of 25 feet. Finally, all through the Mesozoic the mammals are small and are not much in evidence, but with the vanishing of the dinosaurs comes their rapid ascendancy into the giant rulers of Cenozoic time.

These overspecialized giant forms vanish during or shortly after the times of either marked climatic or environmental changes. It is not bulk alone that brings about their extermination, but this in combination with a changing environment — the disappearing of their habitats and the vanishing or alteration of their food, to which they can not adapt themselves. It often happens that the smaller animals also die out at these times, but always there are some stocks left to find an unoccupied kingdom before them; and into it they spread, adapting themselves to the new conditions, and becoming in turn the lords of their time.

E. D. Cope denominated this pulsing or cyclic development of life as the *survival of the unspecialized.* He expressed it as an evolutionary law, namely, that the highly developed or specialized types of one geologic period are not the parents of the types of succeeding periods, but that the descent is derived from the less specialized of the preceding ages.

Osborn concludes that extinction of species begins with the diminution in numbers of any form, which may arise from a chief or original cause, followed by other causes that are cumulative in effect. "From weakening its hold upon life at one point, an animal is endangered at many other points."

Parasitism. — It has been said that more than one half of the animal forms known are parasites and that all organisms, even the parasites themselves, are infested with them. The human species is known to harbor more than fifty kinds. Parasitism is one of the best examples of the interlocking dependence of organisms. The hosts may become immune to their parasites, but when long immunized forms come into contact through migration with those that have not hitherto been infested by these parasites, the newly attacked species may become sick to death and be totally destroyed. Therefore the times of wide-spread intermigration of plants and animals across newly made land bridges are the ones when the parasitic diseases are most destructive in blotting out parts of floras and faunas. Parasites, even in the immunized hosts, must be a great factor in evolution. (Eccles.)

Interorganic Changes. — In the previous paragraphs some of the more striking physical causes that lead to changes in the organic world have been mentioned. Now we are to see, but briefly, some of the reactions among the organisms themselves, and the train of interlocking consequences that leads to specific destruction or change into new adaptive forms. Most organisms are dependent upon one another; for instance, most flowers would not fructify without the searching of insects for pollen or nectar, and mammals are interlocked with external and internal parasites. And so organic interdependence goes on from the higher to the lower organisms. Change one link in the chain of interdependence, and a cycle of reactions is bound to follow until the balance of nature is again established.

Critical Times in the Organic World. — The rocky shell of the earth is nearly always in slow movement, warping slightly up and down in compensation for internal changes, and periodically parts of it are pushed high into mountains. In other words, there are in the

history of the earth long times of slight adjustment, physical and organic, punctuated by shorter ones of marked deformations. It is these times of mountain making that condition ancient geographic history, crustal unrest with consequent marked changes of climate, and organic evolution.

The periods begin with small seaways, following the time of continental elevation and sea withdrawal at the end of the previous period. The middle time of a period is a longer one of more or less crustal stability and more or less extensive floodings of the continents by the oceans. Here again we see a constant change in the geography and climates of the dry land and marine realms. Each one of these active and decisive movements occurs as a rule toward the close of a period, but toward the end of the eras (late Proterozoic, Permian, Cretaceous, Pliocene) many more regions of the earth's crust are rising into mountains. Then result the greater alterations in geography and in life, when the marine waters are more or less completely withdrawn from the continents, the lands are highest, and the climates are decidedly zonal, with cool to cold regions. *Critical times* in varying degrees are upon the disorganized organic world.

The term "critical periods" was proposed by Joseph LeConte in 1877, and in 1895 these were defined as the times of very general re-adjustments of the crust of the earth and therefore of widespread changes in physical geography. At these times the physical changes are so great and so general as to affect profoundly and widely the climates of the earth, and in this way give rise to marked changes in the organic world. These critical times or revolutions are, however, not catastrophic, since the slowly evolving crustal movements endure through millions of years (study diagram, p. 445).

Summary. — We have seen how the climates of the geologic past have fluctuated from long times of slightly altering mild conditions that are locally variable between moist and dry, to the shorter punctuating ones of cool to cold conditions. This variability of climate appears to be largely governed by the changes of the earth's surface, not alone through the change of lowlands into highlands with the resulting cooled climates, but also because of the periodic wanderings of the oceans as shallow seas over the continents. The greater the marine areas, the wider in extent are the resulting equable moist climates; and the smaller the floodings, the more contrasting are the climates of the lands. A look back through the geological ages appears to reveal the earth's surface and its climates as in ceaseless flux, but after all, since geologic time is exceedingly long, the mean condition of any given time lasts for ages.

When the physical environments of the organisms do not change excessively, then the floras and faunas quickly adapt themselves to them. Such changes do not bring out marked alterations in the floras and faunas. When, however, the changes are decided and especially when the climate becomes cold and the topography is rugged, then the life is subject to vast changes because critical conditions are upon it. It is then that are noted the greatest changes in the life assemblages, the vanishing of the most specialized and the giants, and the appearance of new creations, as it were, out of the small and less specialized — an emphasizing of the law of the survival of the unspecialized.

Through the periodic moving of the earth's surface, and the consequent succession of climatic cycles, we see the struggle for survival among the plants and animals resulting in the retention of the most fit through adaptation to the changing environments. And in the perspective of the past we see the ups and downs of life, its pulsing throughout the geologic ages. In it all there is, however, a progression to greater individual complexity in an increasingly intricate organic complex that attains to higher and higher mentality.

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CHAPTER XXXIII

THE BEGINNING OF MESOZOIC TIME: THE TRIASSIC PERIOD

Mesozoic Era

To the founders of Geology the Mesozoic rocks were known as the "Secondary" formations, situated above their Primary (Paleozoic and older eras) and beneath their Tertiary (Cenozoic) divisions. To them the Mesozoic was the middle or medieval time of the earth's history, and they therefore selected a name meaning *medieval life* to express that idea. It is now well known that the Mesozoic formations are far from holding the middle time of geologic history, but the life known to geologists is medieval in character and it is in this sense that the term is used.

Divisions of Mesozoic Time. — The Mesozoic era, though of very long duration, was only one half as long as the Paleozoic, or even less, but it was twice as long as the Cenozoic. In Europe, this era is divided into three periods — the Chalk or Cretaceous, the Oölite or Jurassic, and the New Red sandstone or Triassic; but in America the Mesozoic is sometimes divided into four periods, by separating the great chalk formations into a lower and an upper series, known respectively as Comanchian and Cretaceous. These periods, on the basis of organic change, and because of the decided movement that gave rise to the Sierra Nevada Mountains, can be grouped naturally in America into two sub-eras, the Early Mesozoic (Triassic and Jurassic) and Late Mesozoic (Cretaceous).

Characteristic Life of Mesozoic Time. — Gideon Mantell as long ago as 1831 called the Mesozoic the *Age of Reptiles*, because those animals then dominated the world. The Mesozoic Reptilia were very diversified in form and adaptation — small to gigantic, sluggish to agile — but their mentality was always of a low order. Scott tells us: "They filled all the rôles now taken by birds and mammals; they covered the land with gigantic herbivorous and carnivorous forms, they swarmed in the sea, and, as literal dragons, they dominated the air."

Out of the reptiles early in the Triassic arose the small and insignificant reptilian and egg-laying mammals, and from another

stock came the reptilian birds, with an abundance of teeth; both stocks at the close of the Mesozoic era began to modernize, one into the suckling mammals and the other into the toothless birds. Among the Paleozoic amphibians, the stegocephalians vanished with the Triassic, and their only living remote descendants are the salamanders and the greatly modified frogs of late Jurassic (Morrison) origin.

The dominant Paleozoic animals, the trilobites, sea-scorpions (eurypterids), blastids, tetracorals, and graptolites, were gone, while the crinids, echinids, and brachiopods were greatly modified and the kinds were not only characteristic of the era, but more like those of the present. The bivalves and gastropods were undergoing great change in the Early Mesozoic, and the culmination of their evolution was attained in Cenozoic time. Oysters have been abundant since the Jurassic. The ammonids of the Permian gave rise to a wonderful evolution in the Triassic but were almost exterminated at the close of this period; another rapid evolution took place in the Jurassic, with the Lower Cretaceous they began to show decline, and at the close of the Cretaceous they had disappeared. Among the marine invertebrates none were more significant of Mesozoic time than the ammonids.

The floras had also undergone great changes, since all of the more significant spore-bearing plants of the Paleozoic were practically gone and the ancient ferns were changing into the modern stocks. The older seed-bearing plants had given rise to more modern conifers, maidenhair trees (gingkos), and cycads in greatest variety. Giant rushes, modernizing ferns, and tree-ferns also were present. As the cycads dominated the floras of Early Mesozoic time it is called the *Age of Cycads* (see Figs., pp. 27 and 386). The forests of early Mesozoic time must have displayed a variety of foliage never equalled before or since, and it is probable that the various shades of green were enlivened by fructification cones of dull red or purple colors as is the case to-day among the cycads and conifers. If sweet odors due to nectar secretions were then present, it was in all probability to a limited extent. With the Lower Cretaceous, the modern flowering plants and insects (beetles, flies, butterflies, bees, wasps) took their rise, and we may say, in fact, that much of the modern floral and insect world has been established since early in the Cretaceous.

Triassic Period in Europe

The Term Triassic. — In Germany at the opening of the last century, the three-fold stratigraphic nature of the Triassic was already well known, Germany and the Alps being the regions from

which most of our knowledge of Triassic time has come. In the north, the Triassic begins with the variegated sandstone member (Bunter, 650–2000 feet) of fresh-water origin, which is overlain by a more or less thick shell limestone (Muschelkalk, 800–1100), made by an epeiric sea that spread northward into Germany from the mediterranean Tethys. This sea again vanished and local coal swamps appeared; then followed variegated continental deposits that are mostly of a red color, along with beds of gypsum and more rarely of salt (Keuper, 800–2000). This is the *Germanic phase* and to it Alberti in 1834 gave the name Triassic because of its three-fold development. In England there is no Muschelkalk and all of the Triassic is of continental origin; originally these deposits were known as the New Red sandstone. In France, the Triassic is often called the Saliferous period, because it has here important beds of rock salt.

In the Alps, and especially in the Tyrolian region, where the deposits are of marine origin, with a wonderful array of fossils, the Germanic classification cannot be applied. Here the Triassic is divided into six series, and as they are of normal marine sediments, this development is spoken of as the *Alpine* or *normal phase*. The latter has become the standard of correlation for the marine strata of this period, while the Germanic phase interprets the land conditions and the diastrophic movements.

Gümbel holds that the area in which was formed the Germanic phase of the Triassic was separated from that of the Alpine or normal marine development by a low mountain tract — the Vindelian mountains — that existed throughout the entire Mesozoic from Italy and Sardinia along the Bohemian-Bavarian boundary to the central plateau of France.

Triassic of North America

Significant Things about the Triassic. — Probably the most striking fact about North America in the Triassic, and in the Jurassic as well, was its emergent condition. The only flooding by the oceans was along the Pacific border and in Mexico. This condition is sometimes spoken of as *geocratic*, that is, with the land areas predominating. Because of this emergent condition, desert climates prevailed, and the geologic record therefore consists largely of coarse red fresh-water deposits, with scattering fossil plants and bones of reptiles. Along the Pacific coast, however, there are widespread marine formations that abound in molluscan fossils, among which the ammonites are most significant. Corals and reef lime-

stones are also wide-spread. In these marine deposits, which are usually very thick, there are vast amounts of volcanic ash and lavas, attesting to an abundance of volcanoes from California far into Alaska. Lavas also flowed widely in the fault-troughs of eastern North America from Nova Scotia to Virginia. The Palisades along the west shore of the Hudson River and East and West Rocks at New Haven, Connecticut, are also lava-like rocks, but of a type which congealed deep below the surface and have since been exposed through the erosion of their covering strata.

The Appalachian Revolution (see p. 426) not only raised the eastern border of North America into a mountainous tract, but continued the continent to an unknown distance, at least some hundreds of miles, into the Atlantic Ocean as well. Therefore the greater eastern half of the continent remained above the sea for a very long time, certainly to the end of the Jurassic. A further reason why the sea did not spread over this region lies in the fact that another period of elevation set in at the close of the Triassic — the Palisade Disturbance. Hence the geologic record is one of erosion, the making of land forms, and the accumulation of continental deposits in thick series. Along the Pacific border, however, there is a long marine sequence that is correlated best with the Asiatic records, and the waters also spread their sediments over great areas of the western Cordilleras, but all later deposits are fresh-water red muds and sandstones. The Triassic of North America is therefore displayed under three different regional sedimentary and faunal phases: (1) Pacific coast normal marine, (2) western Cordilleran fresh-water, and (3) Atlantic border intermontane continental deposits.

Subdivisions of the Triassic

Marine and Continental Phases of Europe			American Pacific	Western Cordilleran	American Atlantic	
Upper	Rhætian Norian Karnian	Keuperian	Swearinger Hosselkus	Vast areas of sandstones and red beds	Brunswick Lockatong Stockton	Newark Series
Middle	Ladinian Anisian	Muschelkalk or Franconian	Pit			
Lower	Skytian	Bunter or Vosgian	Unnamed shale of Inyo Mts.	Thaynes Woodside		

The physical conditions and the absence of the sea in eastern North America in Triassic time were also repeated in South America, most of Africa, and northern Europe and Asia. In other words, the revolution at the close of the Paleozoic

was decidedly positive and extended over the greater part of the earth, leaving most of the continents standing well above sea-level, while the main areas of oceanic overflow were the bordering lands of the Pacific and Tethys. Therefore the Triassic the world over was a geocratic time, when the continents were largest. During Middle Triassic time only did Tethys flow widely northward over Europe and lay down the well known epeiric limestones called the Muschelkalk. In nearly all the lands mentioned the climate was semiarid to arid.

Newark Series

The Appalachian Mountains, consisting of many ranges that were completed in Permian time, were even then undergoing reduction, and all of the products of erosion were being swept into the oceans. Seemingly the same conditions continued into the Triassic, for no one has yet found among the few fossils of this period in eastern America any that are indicative of the earliest epoch. The fishes, Eastman says, indicate early Upper Triassic, while the plants Stur and Knowlton regard as of the same time. In any event, the Triassic deposits of Nova Scotia (see Pt. I, Fig., p. 99) lie upon the nearly peneplained and truncated edges of Paleozoic formations ranging from the Champlainian to the Pennsylvanian. In Pennsylvania and New Jersey the Triassic lies on the planed edges of the Lower Paleozoic. From this evidence we see, further, that the folded structures of Permian time had suffered profoundly from erosion even by the beginning of Newark deposition.

Newark Fault-troughs. — The term *Newark*, taken from Newark, New Jersey, was proposed by Redfield for the red sandstones found upon the Piedmont Plateau (Fig., p. 458). Beginning with about Middle Triassic time, the several regions of Newark sedimentation — Nova Scotia, Connecticut, and New Jersey to North Carolina — began to fault along one side, and certain narrow but long areas began to subside as troughs, while the adjacent spaces stood firm as unmoved blocks (horsts), or actually rose. In this way the median arch and the lateral horsts were reëlevated from time to time into more or less high lands, and their eroded material was moved by the rivers into the subsiding valleys. Such major fault lines occur along the eastern side of the Connecticut valley (here the displacement is about 2 miles) and others are known in the western parts of the Triassic areas of Maryland, New Jersey, Pennsylvania, and Nova Scotia. In this way the constantly rejuvenated highlands were subjected to quick erosion, and into the sinking valleys on the sides of the horsts the aggrading rivers brought down vast amounts of sediment, the present Triassic formations. Because of their subsidence the loading troughs also came to lie below the plane

of erosion and so were preserved throughout subsequent time. In the Connecticut valley there are from 10,000 to 13,000 feet of continental deposits (Fig., p. 459), in New Jersey and in southeastern

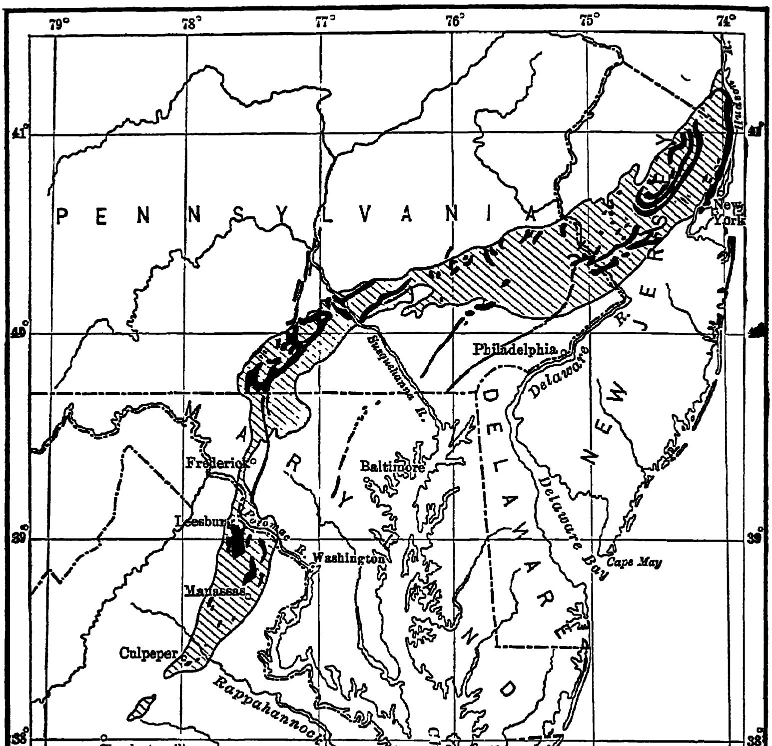

Fig. 149. — Triassic continental deposits (ruled areas) and igneous rocks (solid black) of the Atlantic States. The Palisades are shown along the Hudson River, and reappear at the surface to the east of Princeton, New Jersey. U. S. Geol. Surv.

Pennsylvania the maximum thickness is said to be over 20,000 feet. Here the eastwardly flowing rivers may have headed as far west as the present Allegheny plateau. In Pennsylvania, the trough of sedimentation seemingly subsided 3 miles during the Triassic

period. Southward these deposits thin rapidly, and to the west of Richmond, Virginia, they are about 2500 feet thick, and in North Carolina 3000 feet (Fig., p. 458).

The character of the formations and the geological structure of the Newark troughs are analogous to those which exist at the present time in the Great Valley of California and the Sierra Nevadas. There, uplift on the east and downsinking on the west during the later Cenozoic have given rise to profound erosion of the uplifted side, the Sierra Nevadas, and transfer of sediment onto the sinking floor. A fault zone separates the Great Valley, the downsunken side of the block, from the Coast Range. The latter also contributes sediment to the valley, but the greater part comes from the crystalline rocks of the Sierras on the east. (Barrell.)

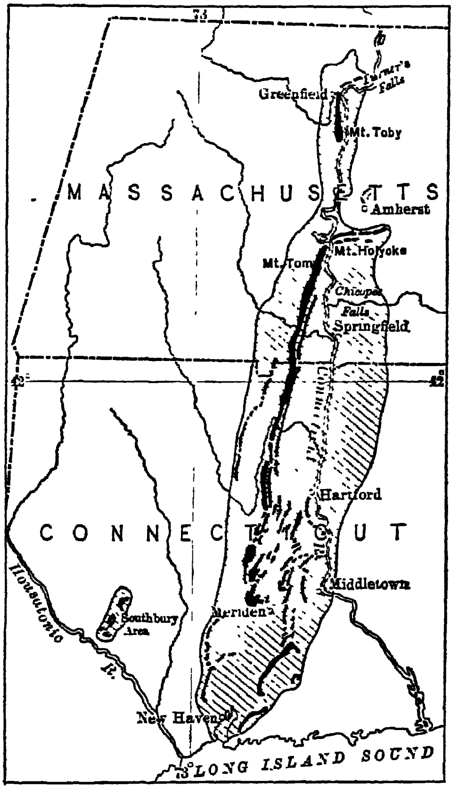

Fig. 150. — Triassic continental deposits (ruled areas) and igneous rocks (solid black) of the Connecticut valley. U. S. Geol. Surv.

Igneous Material. — In all of the areas from Nova Scotia to North Carolina are found igneous rocks that in the lower strata occur as intruded sheets and dikes of trap (diabase), and higher up are extruded sheets of basaltic lavas in thicknesses up to 900 feet (Figs., p. 458, and opposite). These are seen to best advantage along the Hudson River of New Jersey, where they make the well known Palisades, whose vertical walls of columnar rock exhibit the edge of a great intruded sheet of diabase (Fig., p. 460). Although the remains of small volcanoes have been found in Connecticut there seem to have been no great ones at this time, and the molten material welled up repeatedly toward the close of Newark time through fissures situated in the deepest parts of the subsiding areas and near the great faults, and the lavas were either intruded into the sediments or for the most part flowed widely throughout the valleys of sedimentation and

Fig. 151. — Palisades of the Hudson River along the New Jersey shore. Note the columnar intrusive diabase above. Photograph by W. H. Rau.

Fig. 152.— Quarry face in lava sheet of trap or diabase about 100 feet thick, making Orange Mt., near Orange, N. J. Note curving-radiating columns above (8–10 inches thick), and large vertical ones below (3–4 feet across, see inset above). Columnar structure due to shrinkage, and unequal size of columns caused by variable loss of heat in the change from a hot rock to a cold jointed one. See Iddings, Amer. Jour. Sci., Vol. 31, 1886, pp. 321–330. Photograph from H. B. Kümmel.

away from the horsts and rising blocks. Undoubtedly the great subsidences of the sinking valleys fractured the earth's crust deeply enough to let the molten magmas rise into the higher strata and even to flow out as lava on the surface of the Triassic basins.

Character of Sediments. — From northern Virginia to Nova Scotia the Newark sandstones and mudstones are prevailingly red in color and consist almost throughout of conglomerates, sandstones, and shales. All of the material is poorly washed or assorted, and in most places is a heterogeneous mass of detritals, with the greater part of the conglomerates, fanglomerates (Longwell 1923), and coarser sandstones situated near the fault scarps whence they came. The great bulk of the material is from igneous and metamorphic formations, showing that the higher lands lay to the east in the Piedmont Plateau (the rolling land east of the Blue Ridge, see p. 311) of eastern Appalachis, which is made up of Archeozoic and Proterozoic igneous rocks.

Nowhere have the Newark strata yielded a single marine fossil, all of the recovered organisms being those of the land (plants and vertebrates) and of fresh waters (fishes, bivalves). Actual remains of plants and animals are always rare in red deposits, due to the complete oxidation of the sediments during deposition, and the common organic evidence therefore consists of footprints or autographs made by quadrupedal and bipedal terrestrial reptiles (chiefly dinosaurs) (see Figs., pp. 474 and 480). The plants and fishes occur in dark to black shales which are evidently the mud deposits of lakes replete with water plants. The other sediments are much cross-bedded, abundantly sun-cracked, rain-pitted (Fig. 153, p. 462), and rippled, with the feldspars undecomposed; they are the erosion material of a high land of crystalline rocks, deposited in a semiarid climate with hot summers and possibly cold winters. (Barrell.)

Connecticut Valley. — In the Connecticut valley the Triassic is readily divisible into three series because of a great medial zone of lava flows. The *upper series* embraces the many quarries about Longmeadow, Massachusetts, and Portland, Hartford, and Middletown, Connecticut, and consists of coarse sandstones, conglomerates, and shales, about 3500 feet in thickness, with an abundance of reptilian tracks, chiefly dinosaurian. Very rarely, however, is a skeleton or even a bone of a reptile found, though Hitchcock and Lull have described ninety-eight different kinds of vertebrate tracks. The *middle series* has at the top the posterior lava (trap) sheet, 100 feet thick, beneath which are the posterior shales with land plants and ganoid fishes, attaining a thickness of 1200 feet; then come the main lava flows, 400 to 500 feet thick, followed by the anterior shales from 300 to 1000 feet thick, with plants, fishes, and tracks of dinosaurs; at the base is the anterior lava sheet, 200 to 250 feet thick. The *lower series*

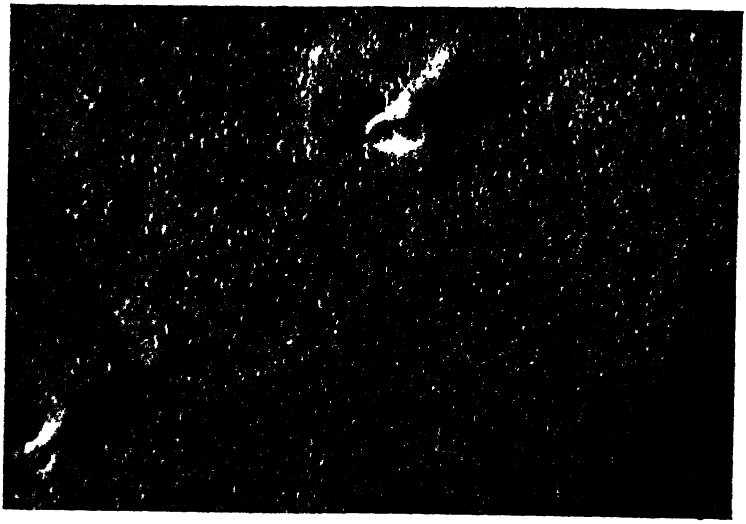

Fig. 153. — Natural casts of rain imprints and dinosaur tracks on a fine-grained sandstone. Peabody Museum, Yale University. Also see Fig., page 473.

Fig. 154. — West Rock, New Haven, Conn. Above is the jointed and columnar intrusive trap or diabase, resting on the eastwardly dipping red Triassic sandstone.

consists of coarse granitic sandstones, frequent conglomerates, some shales, and intrusive traps such as those of East and West Rocks at New Haven, with a united thickness of 5000 to 6500 feet. Fossils are very scarce in this lower series.

Coal Beds. — In the Upper Triassic areas of Virginia and North Carolina there is much fine-grained, black, bituminous slate, with decidedly local bituminous coals, and rarely a zone of black-band iron-ore. The coal beds vary in thickness from a few feet to 13 and even 26 feet. Plants are common here, and of these eight are conifers, twenty-three cycads, six rushes, and thirty-five ferns. Among the latter occurs the broad-leaved giant fern (*Macrotæniopteris*, Fig., opposite). Very rarely are seen amphibia, reptiles, and reptilian mammals (*Dromatherium* and *Microconodon*, Fig., p. 475). These dark deposits with coal swamps, in which Lyell also reports many rushes that still stand vertically, show that the climate of the area of sedimentation was not always and everywhere semiarid, but that locally there were humid climates, with swamps having an abundance of cycads, ferns, and rushes.

Fig. 155. — Giant broad-leaved Triassic fern, *Macrotæniopteris magnifolia*. U. S. Geol. Surv.

Upper Triassic coals are also known in Mexico, Argentina, Australia, India, Asia, and southern and northern Europe.

Palisade Disturbance. — At the close of the deposition of the Newark series, crustal deformation again set in, apparently on a considerable scale, from Nova Scotia to South Carolina, and this makes a natural boundary between the Triassic and Jurassic. Everywhere this new area of deformation lay east of the Appalachian foldings, whose trends the Palisade block mountains nevertheless closely followed. The former mountains had been folded and overthrust, due to shortening of the earth's crust, but now the surface was torn apart, resulting in numberless fractures and faults (tensional) of varying magnitude, and moving the strata in each basin into a series of monoclinal blocks, that is, all tilted in the same direction. As a

result there were formed chains of block mountains, the Palisade mountains of Dana, probably comparable in height to the Sierra Nevadas of to-day.

The Palisade mountain system comprised eight to ten independent ranges. They occurred at intervals over a region 1000 miles long, extending from Nova Scotia southwestward to the northern limit of South Carolina. The ranges were from 10 miles to about 350 miles in length and their general course was closely parallel to that of the Appalachian Mountains. The Connecticut River range was 120 miles long, and the Palisade range, extending from southern New York, on the Hudson, into Virginia, was 350 miles long.

The dip of the beds is, with rare exceptions. monoclinal, and mostly between 5° and 25° in angle. In the Connecticut valley, it is *eastward,* in the Palisade belt, *westward.* In two North Carolina belts, the eastern has eastward dip, and the western, westward. (Dana.)

" These opposite slopes suggest the sides of a wide mountain arch raised between the Connecticut and the Hudson River, whose axis was continued southward through the region of the New Jersey coastal plain and offshore waters. But the raising of the arch was accompanied or followed by the fracture and settling which show on its sides. Wherever the Triassic sediments have been preserved in the Appalachians they show this phenomenon of tilting and faulting, indicating a general crustal movement. Each block lifted up would form a ridge or mountain, each block let down would form a trough or basin. . . . The lack of any known sediments deposited in basins from the erosion of the fault blocks suggests that general uplift prevailed over the whole Appalachian province and that the differential movement between the blocks was one of different degrees of uplift; that there was nowhere real downsinking. The greatest erosion was on the two sides of the basins facing each other. . . . Yet, in spite of this great crust movement, which could not have been earlier than the beginning of the Jurassic, a peneplain had been developed by the end of that period. This is shown by the fact that the Potomac deposits of the late Jurassic or early Comanche are laid down on a gently hilly surface which was eroded across the Triassic and all the older rocks." (Barrell.)

Marine Triassic of Western North America

Triassic of the Californic Sea. — Beginning in the late Paleozoic, and more especially with the middle and upper part of the Triassic, there developed out of the western portion of the Cordilleric geosyncline a northwest and south-southeast trending geosyncline, the Pacific geosyncline, that opened out into the Pacific across northern California and southern Oregon, and again in southeastern Alaska. The southern portion of this trough was the *Californic sea* and it persisted all through the Mesozoic, but was widest and of most significance during the Triassic and Jurassic. In Cretaceous time it was longest and narrowest, extending from Alaska to the south end of Baja California. To the west of the trough lay two forelands, nearly all of which have since gone into the depths of the

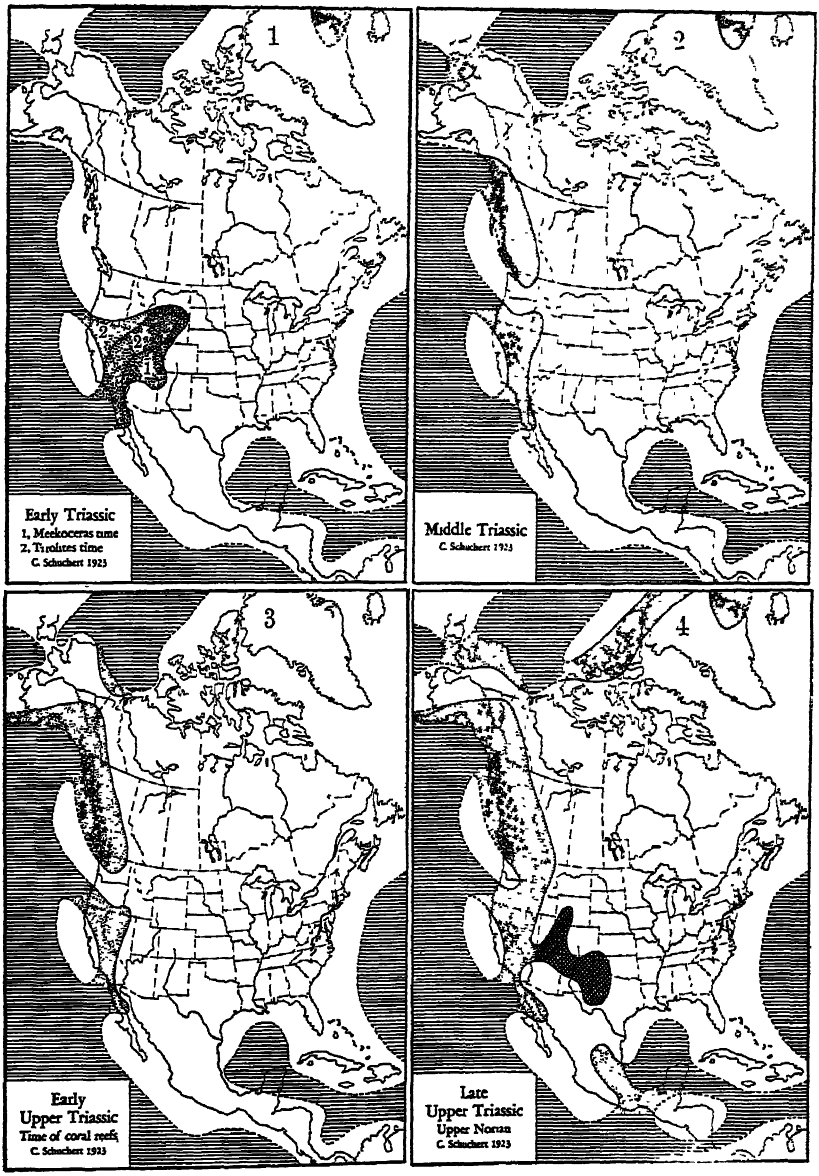

Plate 33. — Paleogeography of Triassic time.

Epeiric seas dotted; oceans ruled. Desert and semiarid deposits either cross-ruled or solid black (along Atlantic piedmont). Volcanic regions indicated by crosses.

Note the absence of the Appalachic geosyncline, and that the marine areas are in the Cordilleric and Mexican regions.

Pacific, leaving the Coast Range of California as their only remnant. (See Pl., p. 465.)

Our knowledge of the West Coast Triassic is best for the states of California, Nevada, Idaho, and Oregon, and is due mainly to the work of Professor J. Perrin Smith of Stanford University. He states that the sequence of Triassic formations and faunas of the Californic sea is unusually complete, and compares favorably with that of most other regions of marine sedimentation. The deposits are usually calcareous and fairly thick (about 4000 feet). The normal marine waters in early Triassic time (Kanab, Moenkopi, Wiser, Thaynes, etc.) spread across California, Nevada, and Oregon into Idaho and Utah, and possibly even into central Wyoming. Before Middle Triassic time this sea withdrew more and more to the westward, due to the rising of the Ancestral Rocky Mountains geanticline, so that the area of the Rocky Mountains and most of the Great Basin region has only fresh-water formations, usually of red colors, and in the main of Upper Triassic age.

The Lower Triassic is about 800 feet thick, the Middle division has about 1000 feet, and the Upper is the thickest, with about 2000 feet. The Middle Triassic faunas are as yet the only ones fully made known, but an estimate based on them indicates that the whole Triassic of this region will yield more than five hundred species, and of these over 70 per cent are ammonids (about ninety genera). All of this, moreover, was true Mesozoic life, for at best there were but few Paleozoic genera then present. The corals (Hexacoralla) made reefs in the Upper Triassic that are known to extend from California into Alaska (60° north latitude), indicating that the waters were warm; this is the coral assemblage of the eastern Mediterranean.

Triassic of the British Columbic Sea. — In the Middle Triassic there appeared a wide and long trough throughout British Columbia, which in Upper Triassic time extended far to the north into Alaska and south into Washington and Montana. This was the British Columbic sea of the Pacific geosyncline, and it persisted into late Cretaceous time. (See Pl., p. 465.)

Along the Pacific border of British Columbia, from Vancouver north to the Queen Charlotte Islands, the Upper Triassic alone is present and it increases to very great thicknesses (Nicola formation), attaining, according to Dawson, to 13,000 feet. The significant feature, however, is not so much the thickness as the fact that more than nine tenths of the rocks are of volcanic origin. The material is that of submarine eruptions — effusive diabases and trachytes, agglomerates, breccias, and tuffs. With these are interbedded zones of marine sediments, argillites and quartzites, that are thin or even

absent to the east, while on Vancouver one such horizon reaches a thickness of 2500 feet.

These western interbedded marine and volcanic deposits undoubtedly extended eastward to the Rocky Mountains, where Upper Triassic strata and faunas occur all the way from Alaska south into Washington. In the coastal mountains of British Columbia they have been eroded away from the granitic bathyliths that rose beneath them toward the close of Jurassic time and that lifted them high into mountains.

Upper Triassic of Alaska. — The Triassic of the British Columbic sea had its widest distribution in Alaska, the marine waters transgressing also from the Arctic Ocean. The first deposits were the Chitistone massive limestones, ranging in thickness up to 2000 feet. Then followed the Nizina limestones in thin strata and with thicknesses up to 1200 feet. These are sediments of warm waters. Finally came black shales with much chert (McCarthy formation) and of cooler waters, having a thickness up to 2500 feet. This geology was fully described by G. C. Martin in 1916.

C. Burckhardt states (1921) that there was orogeny at the close of the Triassic in northern Mexico (Zacatecas).

Emergence of the West Coast. — During the closing epoch of Triassic time (Rhætic), all of western North America became dry land, and it remained above sea-level during the greater part of the early Jurassic (Lower and Middle Lias). Evidence which has come to light since the previous edition of this book seems to show that no mountains were made at this time, as was formerly held (Chitistone disturbance), the submergent waters having been removed apparently by the deepening of the oceanic areas. The time of mountain making here probably came rather toward the close of the Jurassic (Martin).

Volcanoes of the West Coast. — During early Triassic time, throughout western Alaska from the Alaska Range eastward and southward through eastern British Columbia, volcanoes were very active, and there were poured out over the land vast quantities of basaltic lavas, which in places attain depths of between 3000 and 5000 feet.

Along the western border of British Columbia and on Queen Charlotte and Vancouver islands, volcanoes that arose out of the sea were also very active during Upper Triassic time, and in places the lavas and ashes are as much as 10,000 feet thick. In Alaska there was likewise some volcanic activity at this time, but the extruded materials are not of much magnitude.

Triassic Red Beds of the Cordilleran Region

Throughout the Rocky Mountains region south of the Canadian border, but more especially from Wyoming south into western Texas, and in northern New Mexico and Arizona, occurs a series

of red or variegated sandy shales and cross-bedded sandstones (Fig., p. 470), with zones of gypsum sometimes 40 feet thick, that lie over the eroded surfaces of the older formations, and commonly on similar red beds of Permian or Pennsylvanian age. Over a large part of the area the basal conglomerate (Shinarump) is the preserved floor of a desert. Because of the scarcity of fossils in these red beds, the two series are not yet clearly distinguished in all places. In general, however, it may be said that in the eastern and central portions of the Rocky Mountains area these Triassic formations are

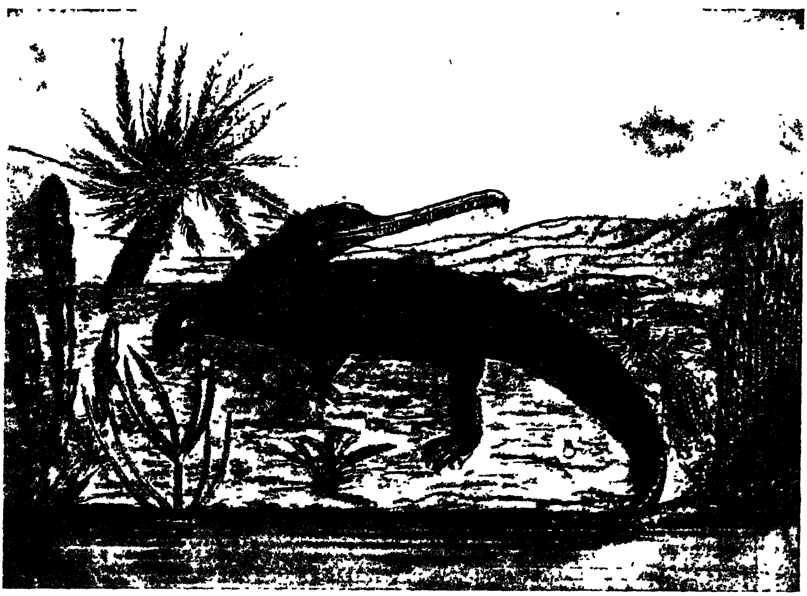

Fig. 156. — Restoration of the Upper Triassic crocodile-like reptile *Mystriosuchus*. The plants are rushes and cycads (upper left-hand corner). After Williston, from his *Water Reptiles*.

thinnest, averaging from 200 to 400 feet thick, and increasing in depth westward to 1000 feet and more. They are all of continental origin.

The fossils of these Upper Triassic red beds are scanty indeed, and none are of marine origin. Here and there fresh-water bivalves occur (*Unio*) and in many places in the upper portion are thin zones with broken bones, known as bone conglomerates. These bones are in part remains of amphibia (Stegocephalia), but mainly of reptiles of the ancient crocodile type (*Mystriosuchus*, Fig., above) and of dinosaurs. Characteristic plant remains are almost absent,

but nearly everywhere occurs drifted wood that is now agatized; in the Petrified Forest of Arizona, near Flagstaff, this is exceedingly common, and great logs may be seen 120 feet long and with diameters of 8 feet, although the common thickness is from 2 to 4 feet (Fig., p. 471).

Appearance of American Deserts

In the desert there is a war of elements — heat, wind, and cloudburst — and among the living a struggle for existence that for ferocity is unparalleled elsewhere in nature. The winds from outside of the desert, for obvious enough reasons, follow the channels through the mountains. During the day the intense heat expands the dry air until it rises, buoyed up by the heavier cooler air of surrounding regions. The hotter the day, the stronger the inward rush of the wind. At night the desert is usually still.

" The shifting sands! Slowly they move, wave upon wave, drift upon drift; but by day and by night they gather, gather, gather. They overwhelm, they bury, they destroy, and then a spirit of restlessness seizes them and they move off elsewhere, swirl upon swirl, line upon line, in serpentine windings that enfold some new growth or fill in some new valley in the waste." (J. C. Van Dyke.)

The sands are ever at work sand-blasting the rocks and wearing them into fantastic form, and in addition the great heat of the day and the marked coolness of the nights causes the rock to peel and split. The latter process, called *deflation*, is as effective in the desert for the weathering away of the highlands and protruding rocks as are water and frost in pluvial climates.

Another marked feature of deserts is that no rivers originate in, or flow out of them, though rivers originating elsewhere do flow through them, as in the case of the Colorado and the Nile.

The driest region of North America to-day lies in northern Mexico, Arizona, Nevada, and Utah. Here the average annual rain-fall does not exceed 10 inches, and in the Mohave desert of Arizona and California it is less than 2 inches. This dryness is mainly due to the fact that the area mentioned is within the " horse latitudes," regions which have calm weather and light variable winds during a large part of the year. In addition, the windward-facing Pacific Coast is bordered by the Coast Ranges, which take out the moisture of the atmosphere as it rises and becomes expanded and cooled going over their summits.

The present deserts of the United States cover a triangular area of 50 000 square miles, with its base on the Mexican border and its

Fig. 157. — Cross-bedded Triassic dune sandstone (De Chelly), Monument Uplift, Arizona. Photograph by H. E. Gregory.

Fig. 158. — Upper Triassic desert sandstone, 700 feet thick, Canyon de Chelly, between Del Muerto and Monument canyons, Arizona. Photograph from W. C. Mendenhall and H. E. Gregory.

apex in north-central Oregon. On the west stand the mountain walls of Baja California, the Sierra Nevadas, and the Cascade Range. Eastward the desert extends to the Pecos River of New Mexico and western Texas.

Succession of Deserts in Southwestern North America. — Over the Great Plains of the western United States, and more especially in the Great Basin country, between the Rocky Mountains and the Sierra Nevadas, occur many continental deposits of sandstones, and more rarely of conglomerates, that are red, pink, or light gray in color. The materials of these deposits are mostly those of water

Fig. 159. — Three silicified logs of Triassic age in Fossil Forest Park, Arizona. U. S. National Museum.

transportation, though at times they are clearly of wind-blown origin, as is attested by the round grains of sand with frosted surfaces and the dune stratification of the sandstones. In the Lower Triassic the red sandstones are muddy, with interbedded red shales and curious concretions, while deposits of gypsum are not rare. In all of these strata fossils are usually scarce and when present are mainly of land plants or land animals. At places chalcedonized logs are occasionally plentiful. The greatest amount of the Upper Triassic deposits occurs in Arizona, Nevada, Utah, southwestern Colorado, and western New Mexico (Shinarump, Chinle, Dolores, Sandstone Spring, Dockum), and the thickness of the formations is often considerable.

Here we have spread before us the records of dry climates, varying from semiarid to decided desert conditions. Some of these desert sandstones are illustrated on page 470.

Red estuarine deposits begin to appear with the late Pennsylvanian, and are of widest occurrence during the earlier Permian and Triassic, an epeiric sea of wide extent being present here during early Triassic times (Kanab, Moenkopi, De Chelly, Wiser, Thaynes-Woodside, Spearfish). The material came in part from the west, from the highlands of Cascadis, and in part from the east out of the Ancestral Rocky Mountains of eastern Colorado and New Mexico. These deposits indicate semiarid rather than arid climates. Then came the truly desert conditions of the later Triassic. In early Jurassic times followed vast deposits of sandstone (La Plata, McElmo) that spread across northern Arizona, eastern Nevada, and western New Mexico into Utah. These materials came either from the west or from the south in northwestern Mexico. Beginning with the Upper Jurassic, however, the deposits are more or less those of inland seas and moist climates, red colors and gypsum being generally absent. From the present atmospheric and topographic conditions, we may conclude that in all probability the succession of southwestern American deserts from late Pennsylvanian into early Jurassic times was due to atmospheric and topographic causes that were very similar to the conditions obtaining at present in the same region.

Life of the Triassic

In the previous pages some mention has been made of the Triassic life of the various American regions, but in this place it is proposed to point out the essentials of the Triassic floras and faunas.

Land Plants. — The Triassic floras are small, as not more than 400 forms are known in all the world, and of these 150 occur in America, with the best representation in Virginia. Practically all the known plants are of Upper Triassic time. Of the Paleozoic genera, nearly all had disappeared. The Triassic flora consisted essentially of rushes, many of them large; ferns, including tree-ferns; and cycads and conifers in many genera whose representatives now live in tropical and subtropical regions (see Figs., pp. 463 and 468). The evergreen trees were dominant in the forests and were as tall as the conifer woods of to-day (Fig., p. 471). In the swamps the rushes made dense brakes like the canes at present, and in general we may say that the vegetation of the Triassic, though far less varied than that of to-day, was rich and beautiful in leaf forms. The distribution of the floras was almost world-wide. While it was not a

luxuriant vegetation, the plants were not dwarfed, as might be expected from the general prevalence of warm semiarid to desert climates. The trees of Arizona show slight annual growth-rings that are probably due to seasonal drought, while those of Spitzbergen have decided ones (perhaps due rather to long seasons of darkness), and it is held by botanists that the climate was warm and mild throughout the greater part of the world.

Insects. — Our knowledge of Triassic insects is almost a blank, for fewer than fifty species are known, and of these about two thirds are beetles, a group of animals that probably arose in the Permian. It may be that the social ants were also present at this time.

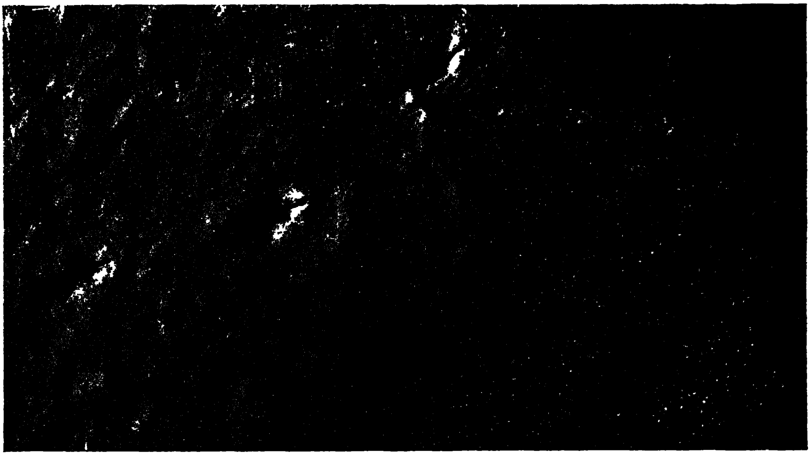

Fig. 160. — Slab of Triassic sandstone, 6 by 3.5 feet, pitted by rain. A large dinosaur (*Steropoides diversus*) walked over the muddy ground before the shower, and a much smaller one (*Argoides minimus*) afterward. Peabody Museum, Yale University. Also see Fig. 153, page 462.

Fresh-water Faunas. — In the Triassic the fresh-water deposits contain *bivalve shells*, and in a broad way we may say that these were not very unlike those of the rivers and lakes of to-day. Of course, the species, and in most cases even the genera, were not the same, but nevertheless the pearl shells (Unios) were abundant. Fresh-water snails, although they arose in the Pennsylvanian, were still rare. The *lung-fishes* were greatly reduced in number, and the dominant forms were the *ganoids*.

Land Animals. — The vertebrates of the land were now very varied and of great interest, exhibiting much structural and adaptive progression over their late Paleozoic ancestors. Among the amphibia the *stegocephalians* attained their culmination in number,

variety, and size. Progression was, however, especially marked among the Reptilia as a class, and specifically among the active dinosaurs (see Pl., p. 480), whose footprints are known in eastern North America in great variety (Figs., p. 473 and below), though good skeletons are exceedingly rare. In Europe, on the other hand, their remains are more common, and, so far as known, the animals were of the same kinds as those of America. From this and other evidence it appears that the great northern continent Eris (Fig., p. 431) was still intact and was the land across which the plants and animals of Triassic time readily migrated to and fro. *Crocodile-like reptiles* of the sprawling type (*Mystriosuchus*, Fig., p. 468) and other active forms (*Aëtosaurus*, Pl., p. 480, Fig. 9) were common. Genuine

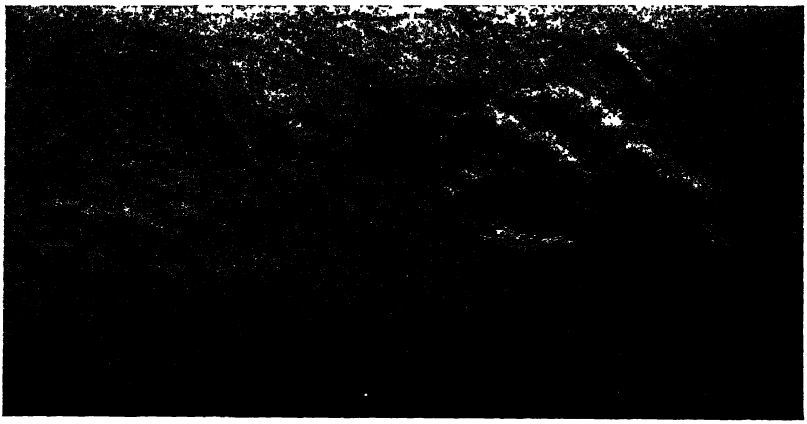

Fig. 161. — Tracks of the largest known Triassic dinosaur (*Otozoum moodii*). Slab 4.5 by 2 feet. Peabody Museum, Yale University.

turtles occur in the Triassic rocks, showing that the group originated in the Permian. No lizards, snakes, or birds are as yet known in rocks of this era.

The *dinosaurs*, however, to be described in the next chapter, were the lords of the land, and they were present in great variety and in great size; in fact, some, known by their footprints only, must have been larger than elephants (Fig., above). In the Upper Triassic they had become adapted to all the land habitats, and the best known American form is the carnivore *Anchisaurus* (Pl., p. 480, Fig. 6).

Archaic or Reptilian Mammals. — Of greatest interest is the rare occurrence in the Triassic of Virginia (two lower jaws, Fig., p. 475) and Europe (isolated teeth) of diminutive reptilian mammals.

Mammals are the most highly organized animals, but these, their earliest known representatives, were very small and very primitive, giving little promise of being the future conquerors of the world (Scott). They probably had their rise in the mammal-like reptiles known as the Theriodonta (Fig., p. 417, the name meaning beast-tooth, and having reference to the resemblance between their teeth and those of carnivorous mammals), which were common in Africa

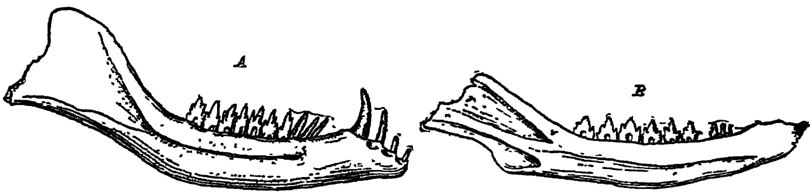

Fig. 162. — Lower jaws of reptilian mammals from the Triassic of Virginia. *A*, *Dromatherium*, × 2; *B*, *Microconodon*, × 3. After H. F. Osborn.

and Europe during the Triassic. The first stock of mammals to arise were the Multituberculata (Fig., p. 516), so named because the teeth have coned or tuberculated surfaces; these were reptilian, probably egg-laying mammals. Of this stock there are left but a few small specialized and degenerate forms such as the duck-billed mole (*Ornithorhynchus*) and the spiny ant-eater (*Echidna*), which are now living in Australia.

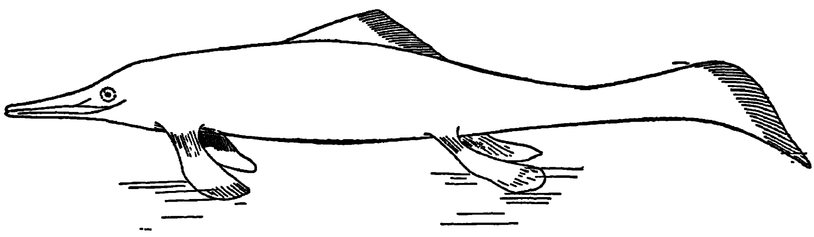

Fig. 163. — Reconstruction of a Middle Triassic fish-lizard (*Cymbospondylus*), found in the West Humboldt Range, Nevada. Length of animal about 30 feet. After J. C. Merriam, from *Nature and Science on the Pacific Coast*, 1915.

Marine Vertebrates. — In previous chapters we have seen how the fresh-water vertebrates were forced to adapt themselves to the land, and how this habitat was attained only after a very long struggle. Now that the reptiles were firmly established on the land, however, we see them going back again to the water, not only intermittently to the rivers and lakes, but permanently into the seas and oceans, where there was a more certain food supply in abundance than is usually the case on the land. Dolphin-like

reptiles, the ichthyosaurs, were abundant in the later Triassic (*Cymbospondylus*, see Fig. 163, p. 475, and other genera of California), and a stock of long-necked, turtle-like reptiles, the plesiosaurs (*Nothosaurus* of Germany) also had its start at this time. Both groups became characteristic of the Jurassic and will be decribed in Chapter XXXV (see Figs., pp. 517 and 519). Here again we see the wonderful extent to which organisms can adapt themselves, for limbs have been changed from walking legs to swimming paddles, and the egg-laying method of rearing the young has been altered to that in which the young are born alive (viviparous development).

Marine Invertebrates. — The seas swarmed with ammonids in great variety, there being by actual count not fewer than 2600 named species and about 250 genera in all the world's Triassic formations (Pl., p. 477, Figs. 4–16). They were not only the most beautiful and characteristic animals of the Mesozoic seas, but also the highest expression of invertebrate evolution in agility and in predaceous and scavenging ability. Some of the species spread widely throughout the world. This upwelling of the ammonids continued into the earlier half of Upper Triassic time (Karnian and Norian) where Diener says there were no fewer than 146 genera. Then in the Rhætic the stock began to die out quickly, since but 6 genera (11 species) were present here. Finally but a single genus (*Phylloceras*) passed into the Jurassic and there quickly evolved into the fullness of Lias forms.

This rapid dying out of the ammonids is thought to be connected with the rise of the marine reptiles, an idea given the writer by his colleague, Carl O. Dunbar. The marine reptiles appear in the Permian, but are not common until Upper Triassic times. Since most of these reptiles are fine swimmers, and of far larger size than the ammonids, it is natural to think that some of them may have fed upon the thin-shelled ammonids, because it is known that in Jurassic times the fish-lizards ate squids. Hence in the rise of the marine reptiles we appear to have the cause for the nearly complete extermination of the ammonids in the late Triassic. However, the seas begin to cool in Rhætic time, and with this change in the habitats the reptiles become restricted to warmer waters, giving the ammonids a new lease of life in the cooler waters. The latter therefore undergo a new and rapid evolution in the early Jurassic, but with the warming seas of later time new stocks of marine reptiles appear, attaining their best development in the Middle Cretaceous (see Fig., p. 559). Again the ammonids die away and finally the more prevalent forms are the bottom-living kinds often referred to as degenerates, but in reality highly specialized stocks (see Fig., p. 576).

The squids originated in the Triassic (Pl., p. 477, Fig. 3) and were common in the Jurassic.

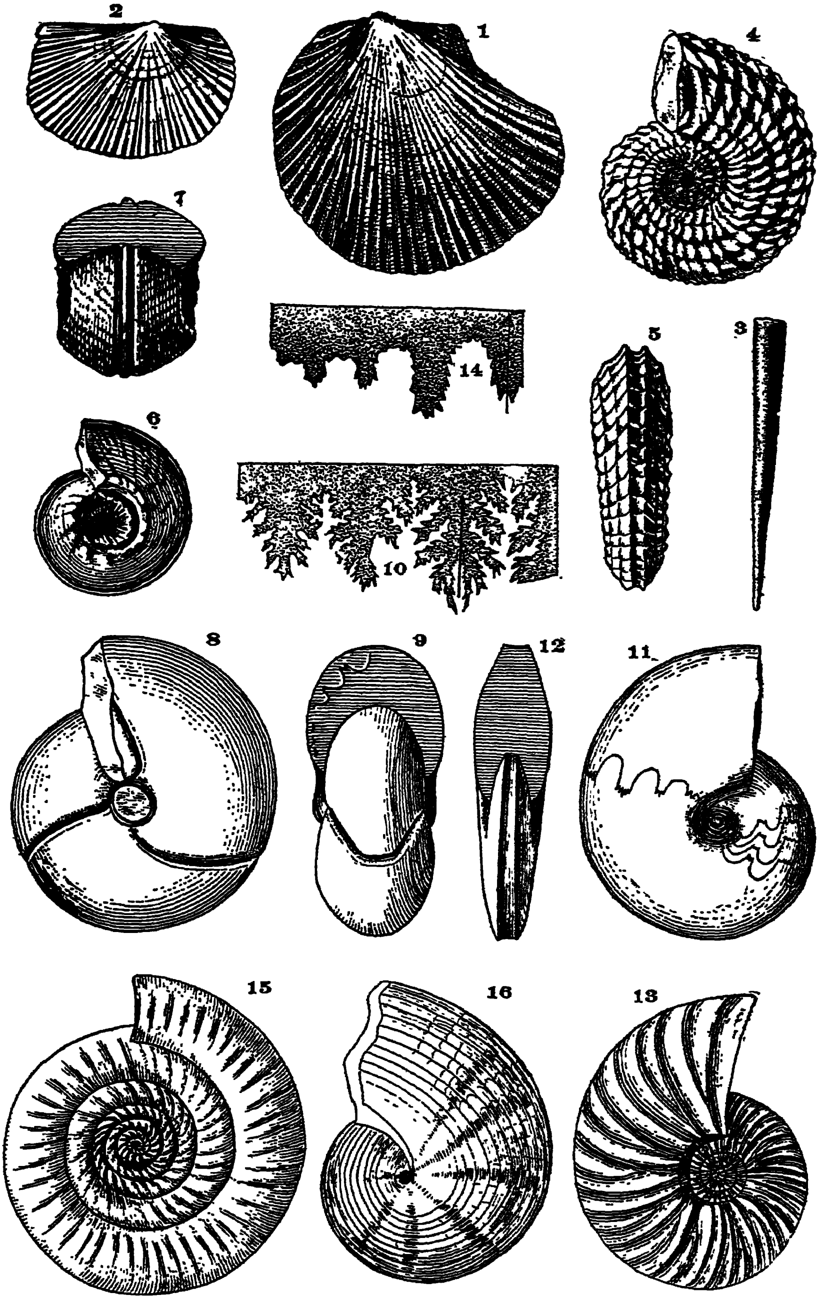

Plate 34. — Triassic bivalves (1, 2), belemnid (3), and ammonids (4–16).

Fig. 1, *Pseudomonotis subcircularis*, × ⅓; 2, *Daonella dubia*, × ½; 3, *Atractites burckhardti*, × ⅓; 4 and 5, *Anolcites meeki*, × ½; 6 and 7, *Tropites subbullatus*, × ⅓; 8–10, *Joannites nevadanus*, × ½; 11 and 12, *Meekoceras gracilitatis*, × ¾; 13 and 14, *Gymnotoceras russelli*, × ¾; 15, *Tropigastrites rothpletzi*; 16, *Sageceras gabbi*, × ½. After J. P. Smith, from the U. S. Geological Survey. (477)

Among the other shelled animals, the bivalves (Pl., p. 477, Figs. 1, 2) and siphonate gastropods were in the ascendancy. The brachiopods, though still common in Tethys, were very rare in the American Pacific faunas and have remained so up to the present time.

In the Upper Triassic appeared the modern reef-building corals (Hexacoralla), which built limestones in Tethys up to 4000 feet thick, while reefs are known elsewhere with many identical species, as in the Himalayas, and in the eastern Pacific from California into Alaska. The modern echinids and lobsters also originated at this time, but were not conspicuous until later. Tethys and the Pacific were the main centers of marine invertebrate evolution.

A survey of the life of the Triassic, contrasted with that of the Permian, shows that *no greater change is recorded in all geologic time.* This was the result of the marked physical changes undergone by the earth during the Appalachian Revolution, making the close of the Paleozoic one of the most critical periods in the history of the organic world.

Collateral Reading

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W. M. Davis, The Triassic Formation of Connecticut. U. S. Geological Survey, 18th Annual Report, Pt. 2, 1898, pp. 9–192.

C. Diener, A Critical Phase in the History of Ammonites. American Journal of Science, 5th series, Vol. 4, 1922, pp. 120–126.

R. S. Lull, Triassic Life of the Connecticut Valley. Connecticut Geological and Natural History Survey, Bulletin 24, 1915.

G. P. Merrill, The Fossil Forests of Arizona. Washington, 1912. See also American Museum Journal, Vol. 13, 1913, pp. 311–316.

I. C. Russell, Correlation Papers: The Newark System. U. S. Geological Survey, Bulletin 85, 1892.

CHAPTER XXXIV

DINOSAURS, THE MIGHTY RULERS OF MESOZOIC LANDS

Introduction

In the chapter on the Triassic something was said about the dinosaurs and their footprints on the sands of time. Now they will be described in detail. Bird-like tracks on the red sandstones of Upper Triassic age have long been known in the quarries of the Connecticut valley. Some of these tracks are but an inch long, and others about 2 feet. Many of them are so like those made by three-toed birds that it is no wonder that the geologists of the first half of the past century regarded them as made by birds. Now, however, they are known to have been made by dinosaurs that ran on their hind legs as do the birds. Some of the imprints are four- and five-toed, but most are three-toed. Similar tracks are now known in Pennsylvania, Virginia, and North Carolina, and in many other lands in rocks of different Mesozoic ages.

The Mesozoic or medieval era was truly the Age of Reptiles, for the lands were then under the control of the "terrible reptiles," named dinosaurs by Sir Richard Owen. What reptiles are and how they are related to the amphibians and the more primitive backboned animals is discussed in Chapter XXX, and this knowledge should make the following account more easily understood.

That the Mesozoic is the time of reptiles becomes all the more clear when we learn from Osborn that eighteen reptilian orders were evolved in this era. Of these, only five groups are now living, the turtles, lizards, snakes, crocodiles, and tuateras.

The medieval floras were also strange in their many rushes, ferns, cycads, and conifers. This plant world was peopled in the main by the dinosaurs, the most extraordinary animals the world has ever seen, as diversified in form and size as are the living mammals. Among them were huge beasts of prey with bird-like feet and eagle-like claws, running on their hind legs after the fashion of ostriches; associated with these were other bipedal dinosaurs, but of sluggish habits and with duck-billed muzzles, feeding on the vegetation of the swamps and water places; hugest of all were the sauropods, vegetarians walking on all fours, with more or less pillar-like legs, long

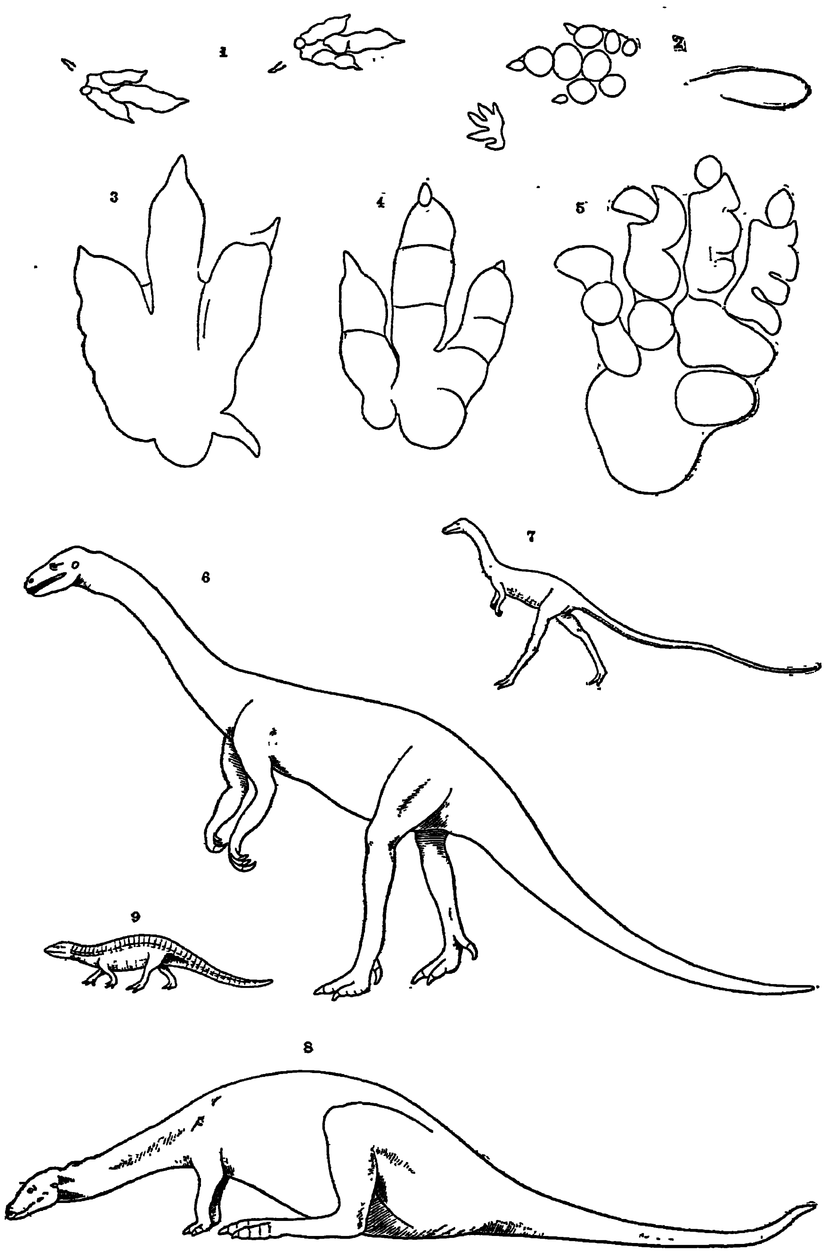

Plate 35. — American Triassic dinosaurs (1–5, footprints; 6, 7, carnivores; 8, herbivore), and a walking, crocodile-like reptile or aëtosaur (9).

Fig. 1, *Anchisauripus* (*Brontozoum*) *sillimani;* 2, *Sauropus barrattii* (*Anomœpus major*); 3, *Gigandipus caudatus;* 4, *Eubrontes* (*Brontozoum*) *giganteus;* 5, *Otozoum moodii.* All $\times \frac{1}{12}$.

Fig. 6, *Anchisaurus colurus;* 7, *Podokesaurus holyokensis.* $\times \frac{1}{24}$.

Fig. 8, restoration of *Sauropus barrattii;* 9, restoration of the aëtosaur *Stegomus.* $\times \frac{1}{24}$.

All after Lull.

snake-like necks, long tails, and a brain weighing less than a pound to govern a body with a weight of about 40 tons, and a length of 60 to 80 feet!

Most curious of all, however, were the armored types, covered with plates and spines; these were also plant-feeders and quadrupedal in gait. Finally, toward the close of the medieval era there appeared a very diversified horde of large rhino-like forms known as the ceratopsians. It is these many kinds of strange medieval brutes that we are to study in this chapter.

PART I. KINDS OF DINOSAURS

The dinosaurs are grouped as follows:

Order **Dinosauria**
- Division **Saurischia.** With lizard-like hip bones. Essentially carnivores
  - Suborder **Cœlurosauria,** or small bipedal carnivores
  - Suborder **Theropoda,** or large bipedal carnivores
  - Suborder **Sauropoda,** or giant quadrupedal herbivores
- Division **Ornithischia.** With bird-like hip bones. All herbivores
  - Suborder **Orthopoda** or **Predentata**
    - Superfamily **Ornithopoda,** or bipedal herbivores
    - Superfamily **Stegosauria,** or armored quadrupedal herbivores
    - Superfamily **Ceratopsia,** or horned quadrupedal herbivores

The dinosaurs are divided into two main groups, based on the nature of the ischium, one of the hip or pelvis bones. The first group, the *Saurischia,* so called because the ischium is like that in lizards, includes the Cœlurosauria, Theropoda, and Sauropoda, of which this chapter will discuss only the last two. The second group, called *Ornithischia* because of the bird-like character of the ischium, includes the Ornithopoda, Stegosauria, and Ceratopsia. The significance of these two types of ischia is discussed later in the chapter in connection with the ancestry of the dinosaurs.

The Carnivorous Theropoda

The primitive light-bodied, long-necked, and long-tailed type of dinosaur, of carnivorous diet, occurs for the first time in the Upper Triassic sandstones of the Connecticut valley. This animal is known as *Anchisaurus* (" near-lizard "). Out of this type developed the later flesh-eating forms, all of which were also bipedal in locomotion, with their greatest variety in Jurassic time. Their fore limbs were often absurdly small in proportion to those behind and were used for catching, holding, and tearing the prey. The hind limbs were long and powerful, the larger bones hollow as in other active beasts of

prey, and the feet were bird-like. The claws were long, curved, and sharp like those of eagles, hence the name Theropoda, which means *beast-footed.* The teeth were sharp, slightly curved, and dagger-like, often with serrate cutting edges to add to their terribleness. No fiercer biting head was ever evolved than that of the king-tyrant saurian, *Tyrannosaurus rex,* of the latest Cretaceous of Montana and Wyoming, — in respect to speed, ferocity, and bodily size the most " destructive life engine ever evolved." In size the Theropoda ranged from several feet long, measured along the back, to 47 feet in *Tyrannosaurus,* with a height in the latter of 18 to 20 feet, and a weight exceeding that of the elephant. The skin in the Theropoda was probably naked, at least it was not defensively armored, though in some cases there may have been scales as in snakes.

Fig. 164. — Two restorations by Osborn of the ostrich dinosaur (*Struthiomimus*), from the Upper Cretaceous of Alberta.

In the late Jurassic (Morrison) of Wyoming there lived a small form known as *Ornitholestes* ("bird-robber"), measuring about 6 feet long down the back, and a very agile carnivore it was. Long in hind limbs, bipedal in locomotion, running and walking but never hopping as do birds, its body and head were balanced by the long tail stretched out behind. (See Pl., p. 483, Fig. 6.)

Out of the carnivorous dinosaurs just described, there was evolved, in adaptation to a changed diet and a different mode of getting food, a lighter and more decidedly bird-like type that finally in the Upper Cretaceous developed into *Struthiomimus* (" ostrich-like "). This was a slender, very long-legged animal, having three-toed bird-like feet, a very long thin neck, small skull, and jaws entirely without teeth, but with a horny beak like that of an ostrich. The fore limbs were comparatively long, with drawn-out slender fingers terminating in rounded straight claws. What these animals fed on is not known, unless it were fruits and very small reptiles and insects (see Fig., above.)

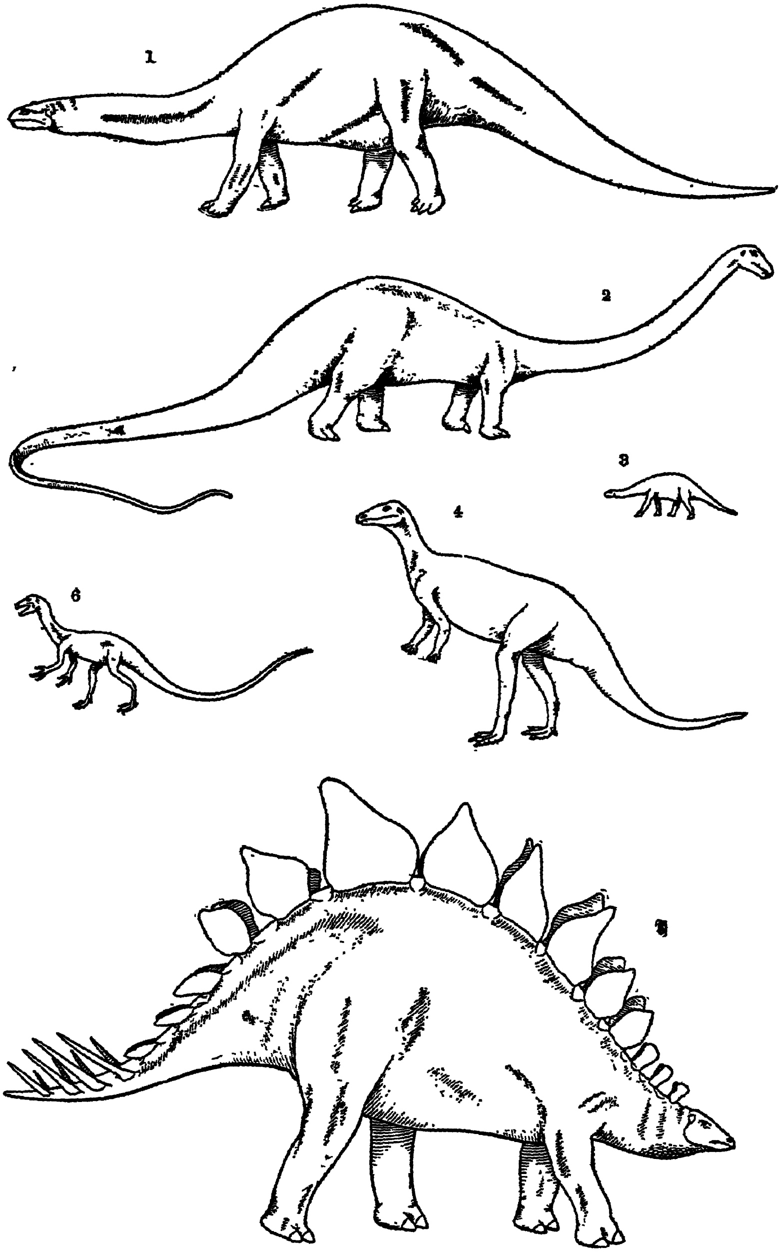

Plate 36. — American dinosaurs, mainly of the late Jurassic (1–3, sauropods; 4, predentate; 5, armored; 6, carnivore).

Fig. 1, *Brontosaurus excelsus;* 2, *Diplodocus carnegiei;* 3, *Pleurocœlus nanus.* $\times \frac{1}{180}$. Fig. 4, *Camptosaurus;* 5, *Stegosaurus ungulatus;* 6, the bird-catching *Ornitholestes hermanni.* $\times \frac{1}{30}$. All after Lull.

The Giant Sauropoda

Professor Lull has shown that among the Upper Triassic footprints of the Connecticut valley there are tracks of carnivore-like dinosaurs that were ponderous and heavy of foot. These are thought to have given rise to the herbivorous sauropods (" reptile-footed ") of Jurassic and later medieval times, the mightiest of all land animals, and necessarily quadrupedal in locomotion.

It is Osborn's belief that as there is never any need of haste in the capture of plant food, the sauropods underwent a reversed evolution of the limbs, from the swift-moving primitive bipedal carnivorous type into a secondary slow-moving quadrupedal ambulatory type.

The sauropods attained a world-wide distribution, being best known in the late Jurassic of North America and East Africa, and in late Cretaceous beds in the United States and western Argentina. The greatest of these was *Gigantosaurus* of East Africa, the largest land animal known, with a length of some 80 feet, 36 feet of which was neck, and a live weight of something like 40 tons. In this form alone the fore limbs were longer than the rear ones. The American *Brontosaurus* (" thunder saurian ") was about 65 feet in length, but heavier in construction, weighing about 37 tons. It was ponderous of body, but with long tapering neck and tail " as though an elephant were deprived of its normal terminals and provided with those of an enormous snake " (Lull). The brontosaurs are thought to have lived for the most part in swamps of river valleys (Rocky Mountains) and in fresh-water marshes along the sea-shore (Africa), detaching the swamp plants with the claws and swallowing them without mastication.

Professor Lull says of *Brontosaurus:* " Its skeleton is a marvel of mechanical design; the bones of the vertebral column are of the lightest possible construction consistent with strength, the bony material being laid down only where stresses arise and reduced to a minimum at other points. The assembled skeleton reminds one forcibly of a cantilever bridge borne on two massive piers — the limbs — between which the trunk represents the shorter channel span, and the long neck and tail the spans leading to the shores. Over the hips is a ridged anchorage formed by the coalescence of several vertebræ, for not only was this the point of origin of the tendons and sinews supporting the 30 feet of tail, but on occasion the whole forward portion of the body, fore limbs, and neck could be raised clear of the ground after the manner of a bascule bridge. In the refinement of its architecture the vertebral column is essentially Gothic,

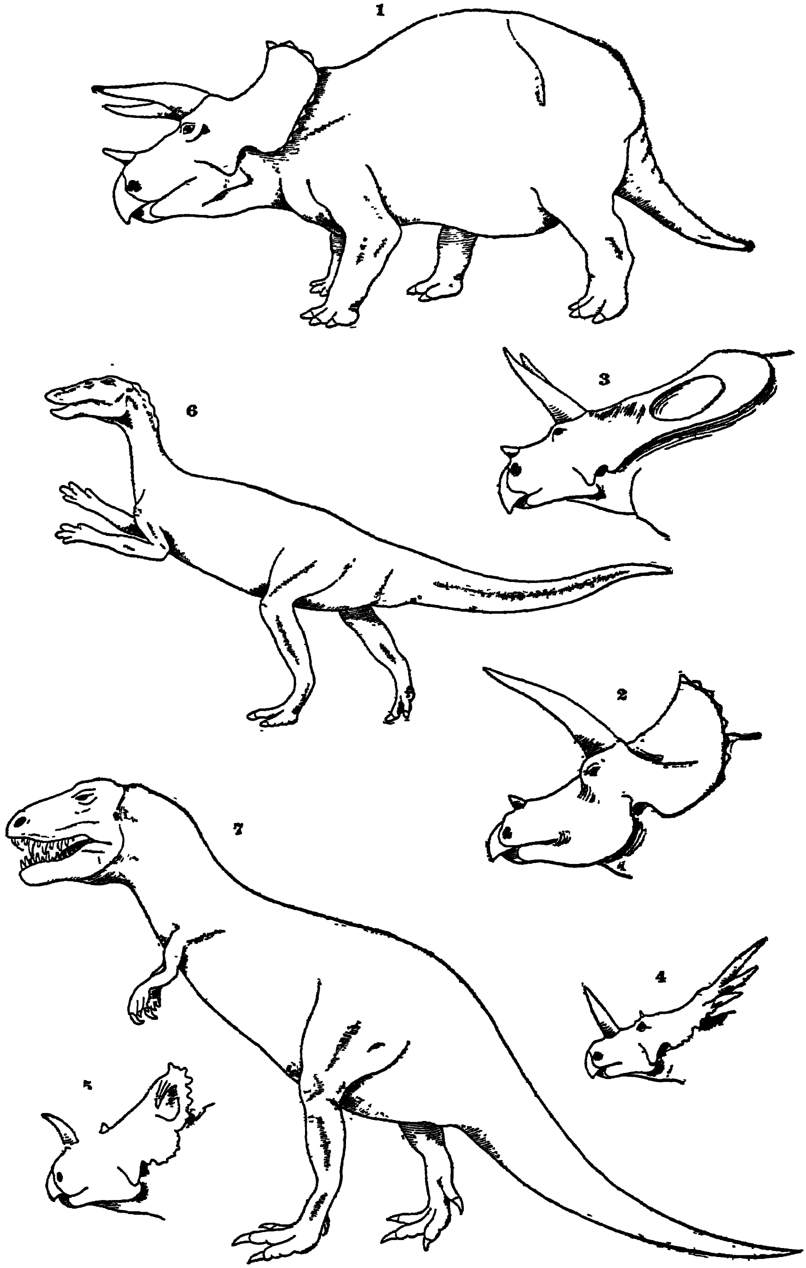

Plate 37. — American Upper Cretaceous dinosaurs (1–5, ceratopsians; 6, predentate; 7, carnivore).

Fig. 1, *Triceratops prorsus;* 2, head of *T. elatus*, the culminating form of one line of Ceratopsia; 3, head of another culminating species, *Torosaurus gladius;* 4, ol er, much horned ceratopsian, *Styracosaurus albertensis;* 5, another older form, *Monoclonius flexus;* 6, bipedal predentate, *Trachodon* (*Claosaurus*) *annectens;* 7, the king tyrant carnivore, *Tyrannosaurus rex*. All after Lull. About $\times \frac{1}{60}$. (485)

with arch, pillar, and buttress, and the freedom of design characteristic of the great fabrics of medieval time."

Diplodocus (so named from the vertebræ, which are double-beamed) was lighter in build though long and slender, with 10 of its 80 feet of length taken up by a whip-lash-like tail of unknown use (see Pl., p. 483, Fig. 2). The ponderous size must have given it a certain immunity from attack, while its chosen haunts kept it out of competition with fiercer kin.

The Bipedal Herbivorous Ornithopoda

Returning once more to the Upper Triassic tracks of the Connecticut valley, we see still other bird-like imprints, but of large size, made by bipedal dinosaurs. These were the Ornithopoda (" bird-footed ") or Predentata, which had no front teeth. The muzzles, however, terminated in a horny sheath, making a beak as in ducks or turtles. These forms lived for the most part in water, where they cropped the plants with the sharp edges of their toothless beaks. In the back part of the jaws were wonderful magazines of wide teeth, long in sequence, and superimposed several deep, with which the predentates ground the food plants before swallowing them. While these teeth were being completely worn away through grinding at the top, new ones were growing beneath in the jaws to take their place.

The hind legs of the bipedal herbivorous dinosaurs were large and powerful, and on land were the essential means of locomotion. Their hands were webbed, and used for paddling, and the long tail was flattened and served to scull about in the water as do the alligators. The duck-bill mouth is further evidence that they dwelt much in water.

Skeletons of bipedal herbivorous dinosaurs are first represented in the American Upper Jurassic by *Camptosaurus* (" flexible lizard ") of Wyoming. In the Cretaceous the stock deployed into a variety of forms, which took more and more, though not wholly, to the swamps along rivers and lakes.

The more primitive of the bipedal herbivorous dinosaurs were those with the duck-like bill. These were the more common kinds during the Cretaceous and included the iguanodons of the Lower Cretaceous of Belgium (see Fig., p. 551) and the trachodons (" rough-toothed") of the North American Upper Cretaceous (Pl., p. 485, Fig. 6).

The skin of the duck-billed dinosaurs is known in seven specimens. In the so called " dinosaur mummy " of the American Museum of Natural History, nearly the entire skin is preserved. This animal

must have lain exposed to the hot sun in a dry climate and so became desiccated and mummified before it was covered over by wind-blown sand. The skin is thin as in pythons and in the different species its bony tubercles are variable in size, form, and pattern, and probably as well in color. Scales were present.

Yet other kinds of beaked and bipedal herbivorous dinosaurs developed out of the duck-billed ones. Among these were the narrow-headed *Kritosaurus* of the Upper Cretaceous of Alberta and the completely aquatic *Corythosaurus* from the same locality, in which the skull bore a high crest as in cassowarys, while the muzzle was small and short.

The Armored Stegosauria

In Jurassic time there developed out of the duck-billed forms a most bizarre stock of heavy-limbed quadrupedal animals, browsing on leaves and twigs. These were the plated and armored types, first discovered by Professor Marsh. Their habitat appears to have been completely away from the water on the dry land, where they were subject to the attacks of their carnivorous colleagues, hence the necessity of a protective armor. They returned to the ancestral locomotion on all fours, and specialized in the production of an elaborate series of bony outgrowths of the skin.

In *Stegosaurus* ("covered saurian") the almost impregnable armor consisted of a double row of variously large bony plates ranging down the back from the head to near the end of the lashing tail, there to be replaced by two or more pairs of long sharp spines, making the tail a "huge battle mace." All of these bony outgrowths were provided with horny sheaths. Over the hip area the plates were more than 2 feet high, 30 inches long, and 4 inches thick at the base. The tail spines attained to a length of about 2 feet. In the skin were other bony nodules. Doubtless when the stegosaurs were attacked, they drew their head and limbs under the body as do the armadillos and porcupines, and relied for protection against their enemies upon their dorsal armature, aided by rapid lateral motions of the great tail with its series of spines. They died out during the Cretaceous, and appear to have been restricted to North America.

Stegosaurus was decidedly "slab-sided" or compressed in body. The head was absurdly small, with a turtle-like beak, while the hind teeth were like those of duck-bill dinosaurs. The relatively small size of the brain is further noted on page 494. (See Fig., p. 488.)

The climax of defensive armoring among the land-living dinosaurs was attained in late Cretaceous times among the sluggish ankylosaurs ("coössified saurian") of Alberta and Montana. Their bodies

were exceptionally broad, but not compressed as in the group last discussed, and supported on short stout legs. The tail was heavy. Though the armor in these forms was less grotesque than that in

Fig. 165. — Skeleton of the armored dinosaur *Stegosaurus ungulatus*, as interpreted by Professor R. S. Lull. From the late Jurassic, near Medicine Bow, Wyoming. Mounted in the Peabody Museum of Yale University by Hugh Gibb, who stands beside the skeleton.

the stegosaurs, it was more effective; the entire body from the nose to the tip of the tail was covered by small bony plates, more or less grown together and lying flat in the skin. The tail ended in a blunt

club of thick plates. In these forms the armoring was in close imitation of that in the armadillos or in the extinct glyptodonts, both of which, however, are mammals. On the neck and tail the armor was in overlapping rings to allow for movement, and the animals when squatting on the ground were proof even against the attacks of *Tyrannosaurus*. Lull has well said that as " animated citadels " these animals must have been practically unassailable.

In the ankylosaurs the heads were very small, triangular in shape, and also covered with bony plates. The teeth of the jaws were feebly developed, but the decidedly horny beaks compensated in securing and cutting the food. The ankylosaurs had a longer history than the stegosaurs, since they appeared in the Lower Jurassic of England (*Scelidosaurus*), continued into the Lower Cretaceous (*Polacanthus*), and were last seen in the Upper Cretaceous of Alberta and Montana (*Ankylosaurus* and *Stegopelta*).

The Horned Ceratopsia

Probably the most interesting of all dinosaurs are the horned types, "strictly American products," first discovered in Wyoming and Colorado by Hatcher. They are interesting because of their varied evolution, chiefly with respect to the head, which was used aggressively and defensively. These horned forms are characterized, in fact, by the hugeness of the heads, in contrast to the comparatively small ones in other dinosaurs. The first form discovered was called *Ceratops* (" horned face "), and this has given the name to the group. They looked somewhat like rhinoceroses. The body was usually very large, barrel-shaped, with four short but stout legs. The tail was massive, but relatively short. The heads were wide and long, being drawn out back over the neck into a prominent protective frill, usually 4 to 6 feet long but reaching 8 feet in *Torosaurus*. In some there was a short and in others a long horn over the nose, and over the eyes there were other horns, which again may be long or short. In *Triceratops* there were three prominent horns. Some of the horns had a length of 3 or even 4 feet, and all the cores of bone were sheathed in horn. In addition, there were still other smaller horns along the edge of the frill, or the latter was drawn out into long horns. The muzzles were also covered with horn as in turtles, and the jaws were replete with cutting teeth. The brain did not exceed 2 pounds in weight. (See Pl., p. 485, Figs. 1–5.)

According to Professor Lull, " In the forms in which the nasal horn was dominant, the crest was imperfect, the animal doubtless charging as a rhinoceros might and impaling its enemy with a sweep-

ing upward thrust of its head; while those whose frontal horns were larger were animals of greater bulk and in them the crest reached its highest efficiency, so that a head-on charge of two rival males was comparable to a joust between panoplied knights, the mighty impact of the lance-like horns being deflected by the shield-like flange. That the ceratopsians did fight, and that most desperately, is shown in the grievous 'old dints of deepe woundes' that remain on many a skull, fractured and healed jaws and horns, pierced crania and crests. As these were only the relatively few wounds which penetrated the bone, what battle-scarred old veterans they must have been after their century or more of life!"

The terrestrial and quadrupedal ceratopsians originated, it is thought, out of small hornless forms, one of which was recently discovered in Mongolia (*Protoceratops* of possibly Lower Cretaceous age). Of this form the skull only is known and it is about 7 inches long. Evidently the ceratopsian stock originated in Asia, but all the horned forms appear ready-made in the Upper Cretaceous (Judith River) of the Great Plains of North America and were among the last of the dinosaurs to die out. Some of them were larger than elephants, weighing in the flesh up to 10 tons. The smallest known skeleton of a fully matured ceratopsian is a little over 5 feet long and but 30 inches tall (*Brachyceratops*).

Part II. Dinosaurs in General

Geographic Occurrence. — Dinosaur remains occur in all continents, but chiefly in North America, Africa, China, and Argentina. The most wonderful known record is that of the American Great Plains. Carnivorous dinosaurs are the most widely spread, in fact, are world-wide in distribution. The same appears to be almost as true of the ponderous sauropods, though they are best known in North America, Africa, and Argentina. The beaked dinosaurs are wholly unknown in South America and Australia.

History of Discovery. — With the building of the Union Pacific Railway and the opening up of the "Great West" came discoveries of fossil bone cemeteries, each more remarkable than the previous one, first in Nebraska and the Dakotas and later in Wyoming and Colorado. To the east of Medicine Bow, Wyoming, the railway passed one of these cemeteries at Como Bluff and here as early as 1872 the station master, Mr. Carlin, collected great bones that he showed to Professor Marsh of Yale, who was then more interested in the living animals of that region. Finally, during the winter and spring of 1877, William Reed, a hunter for the railway, collected more of

these bones, due to Carlin's finds, and again they were brought to the attention of Marsh. In the meantime O. Lucas, a school teacher at Garden Park, Colorado, had also found huge bones of about the same age and these he sent to Professor E. D. Cope, of Philadelphia, Marsh's competitor, while Professor Lakes of the School of Mines at Golden had seen gigantic bones near Morrison, drawings of which he sent to Marsh. The latter then sent into the field S. W. Williston and J. B. Hatcher, with the result that the "fossil wonders of the West" began to pour into New Haven. Since then hundreds of tons of rock with dinosaur bones, in carload lots, have been shipped east, for resurrection and study. Not only was Professor Marsh the first to describe an American dinosaur, but the first dinosaur skeleton to be mounted in this country (*Trachodon annectens*) was placed on exhibition by his successor, Professor Beecher, and now occupies a prominent place in the Yale Museum.

Collecting Dinosaurs. — In the semiarid states of the Great Plains, and especially in their "bad lands," bones may be seen here and there sticking out of the rocks, and in places the ground is literally covered with their fragments. These are the "leads" to skulls and skeletons, just as drifted ores in their trailings lead to the discovery of veins and future mines. As a rule, the remains of fossil vertebrates are much scattered, there usually being present but one or a few of the larger limb bones or vertebræ, more rarely a skull, and least of all, more or less of a skeleton. The best bones are the buried ones, since those exposed through weathering are very much fractured and worn.

A find leads to the use of pick and shovel, and the unearthing of a cemetery begins with horse and scraper or even with dynamite to quarry away the hard capping stone. Bone quarries have been operated each summer through a succession of years and the wonderful relics of the past are garnered through much intelligent labor. In the old days, a find was recklessly picked into and the loose bones shoveled into a bag with the hope that the paleontologist or preparator could piece together the parts, the illustrations of the older books show with what results. The present fine art of vertebrate exhumation began with Professor Marsh, who took his ideas from the surgeon's methods of bandaging broken limbs set in plaster. Now the field worker carefully uncovers the bones in their soft rock and then hardens them with mucilage or shellac. Finally, they are bandaged in plaster of paris, first on the exposed side, and then turned over and completely encased, and shipped in crates or boxes to the museum. Here begins the actual work of resurrection, a long laborious task with chisel and mallet, again hardening the bones with shellac, cementing together the fragmented parts, and finally restoring in plaster those which are lost. The assembling of the bones into an articulate skeleton is the work of the paleontologist, after a study of the remains combined with those of the nearest relatives in the living

Plate 38. — American Pioneers in Vertebrate Paleontology.

1. Ferdinand V. Hayden (1829–1887), Director of the U. S. Geological and Geographical Survey of the Territories, 1869–1879, the first to indicate the bone localities of the West.
2. John W. Powell (1834–1902), Director of the U. S. Geological Survey, 1881–1894, who greatly fostered the collection and description of fossil vertebrates.
3. Joseph Leidy (1823–1891), Professor of Anatomy in the University of Pennsylvania and Vertebrate Paleontologist of the Hayden federal surveys. The first systematic worker in American vertebrate paleontology.
4. Othniel C. Marsh (1831–1899), Professor of Paleontology at Yale University, and Vertebrate Paleontologist of the Powell Survey. The first to bring from the field entire skeletons and to articulate them in their former perfection. To him are due the great collections at the U. S. National Museum and at Yale.
5. Benjamin F. Mudge (1817–1879), Professor of Natural History, Kansas Agricultural College. The first to unearth for Marsh the Cretaceous birds with teeth.
6. John B. Hatcher (1861–1904), whose great ability as a collector in the Great Plains and in Patagonia enriched the museums at Washington, Pittsburgh, Princeton, and Yale, and who also published much on fossil vertebrates.
7. Samuel W. Williston (1852–1918), associate of Professor Marsh, and later Professor of Geology and Anatomy at the University of Kansas, and Professor of Paleontology at the University of Chicago. Leading authority on extinct Reptilia.
8. Adam Hermann (1847–), who developed the art of preparing fossil bones and mounting restored skeletons, first at Yale and then at the American Museum of Natural History.
9. Edward D. Cope (1840–1897), of Philadelphia. Versatile and brilliant paleontologist whose monumental volumes are in the quarto series of the Hayden Survey.
10. William B. Scott (1858–), Professor of Geology and Paleontology, Princeton University. Authority on the extinct Mammalia of North America and Patagonia.
11. Henry F. Osborn (1857–). President of the American Museum of Natural History, New York, and nestor of the third generation of American vertebrate paleontologists.

Plate 38. American Pioneers in Vertebrate Paleontology.

world, and the skeletons set up in museums testify not only to the care of the collector but as well to the skill, ingenuity, and morphologic knowledge of the present-day preparators and paleontologists.

Food of Dinosaurs. — The flesh-eating or carnivorous dinosaurs probably fed on any animals they could get, but more especially, it is thought, on their plant-feeding allies. The food of the latter was the medieval floras, rushes, ferns, cycads, conifers, and gingkos, whose nutritive values were not so high as those of the modern or flowering plants that came in strongly with the Upper Cretaceous. It may be that the latest dinosaurs were feeding on these higher plants, but it appears more probable that the primitive mammals took to them earlier and more completely, and in this way gained the ascendancy over the dinosaurs.

An elephant weighing 5 tons eats 100 pounds of hay and 25 pounds of grain for his day's ration; but as such food is in a comparatively concentrated form, it would require at least twice this weight of green fodder for an animal of the same size. The largest brontosaur probably weighed 37 tons, and it is estimated that its daily food must have been something like 700 pounds of plants.

But here we must curb our imagination a little and consider another point: the cold-blooded, sluggish reptiles, as we know them to-day, do not waste their energies in rapid movements, or in keeping the temperature of their bodies above that of the air, and so by no means require the amount of food needed by more active, warm-blooded animals. Hence these great dinosaurs may, after all, not have been gifted with such ravenous appetites as we fancy. (Lucas.)

Dinosaur Eggs. — A point still unsettled is whether the dinosaurs were oviparous or viviparous, or both — did they lay eggs, or were the young born alive? Until 1923, the only evidence on this matter rested with the Upper Jurassic skeleton of *Compsognathus*, which, according to Marsh, contains an embryo within the abdomen. This form seemingly was viviparous. If, however, we are to be guided by analogy, it might be supposed that, like crocodiles and alligators, most of the dinosaurs laid eggs and left them to be hatched by the heat of the sun. This supposition has recently been confirmed by the American Museum Expedition's discovery of many dinosaur eggs in Mongolia.

Small Brain in Dinosaurs. — Even though dinosaurs attained in the flesh the enormous bulk mentioned, none had a brain exceeding 2 pounds in weight, and in the armored forms (*Stegosaurus*), which were heavier than any elephant, the brain weighed about $2\frac{1}{2}$ ounces, as against twenty times that weight in the elephant. Professor Lull states that in comparing the relative intelligence of the two, "one has to bear in mind the great preponderance of

the cerebrum, the seat of the intellect, over the other part of the elephantine brain, whereas in *Stegosaurus* it constituted scarcely more than a third of the entire brain weight. On the other hand, the nerve canal in the sacrum, that portion of the vertebral column which lies between the hips, is of startling dimensions and shows that this part of the spinal cord from which the nerves went out to the great muscles of the hind limbs and tail was not less than twenty times the mass of the brain. Mentally, *Stegosaurus* was superlatively stupid, depending for defense upon the automatic control of the great muscles after the feeble glimmer of thought had given the initial impulse." The excessively small size of brain in dinosaurs, Osborn states, illustrates strikingly that in animals mechanical evolution is quite independent of the evolution of their intelligence; in fact, intelligence compensates for the absence of mechanical perfection.

In *Trachodon* the brain is smaller than a man's fist and weighs less than a pound. *Brontosaurus* had a brain but little larger, while the large-headed *Triceratops*, with over 10 tons of flesh, possessed a brain weighing not over 2 pounds. Man has an average of about 2 pounds of brain to 100 pounds of total weight, while the dinosaurs did not have one-fourth of this amount of brain to the ton. Or with other comparisons, the brain of the average dinosaur was in proportion to bulk of body a tenth the size of that of a crocodile.

How much of what we term intelligence could such a creature possess? Probably just enough to have eaten when it was hungry, anything more being superfluous. However, intelligence is one thing, life another, and the spinal cord, with its supply of nerve-substance, doubtless looked after the mere mechanical functions of life, and while even the spinal cord is in many cases quite small, the sacral portion is twenty times the bulk of the puny brain. (Lucas.)

Pineal Eye. — In a number of dinosaur skulls there is shown a round opening passing through the bone into the brain cavity. It is sometimes an inch in diameter. In this opening lay, when the animals were alive, a third eye that is known as the pineal eye. A similar eye, rudimentary and degenerating as an organ of sight, is present in some living lizards, connected with the brain and covered by a transparent scale. Vestiges of this eye are also present in the brain of all vertebrates, including man, where it is called the "pineal body," and is about the size of a hazel nut. (See also page 411.)

Dinosaur Ancestors. — The progenitors of the dinosaurs were among the Permian reptiles, and their descendants deployed into all the possible habitats of Mesozoic time. The line started either during the Permian, or certainly not later than the earliest Triassic, in lizard-like reptiles with comparatively long limbs, long tails, five toes on each foot tipped with sharp claws, and a mouth having a series of sharp pointed teeth.

The ancestral dinosaur was undoubtedly a quadrupedal form, distantly related to the crocodiles, and of similar habitat. With the

increasing aridity of Permian and Triassic times, however, speed became of great advantage in the search for food and drink, and this may have led to the adoption of the more rapid bipedal gait.

The dinosaurs probably had two independent origins in lizard-like reptiles, for the hip or pelvic bones are of two distinct types. In one they are crocodile-like and all those that have this type of pelvis are referred to the *Saurischia*, the term having reference to the saurian or lizard-like ischium, one of the bones of the pelvis. The other stock, with the bird-like hip bones, are spoken of as *Ornith-*

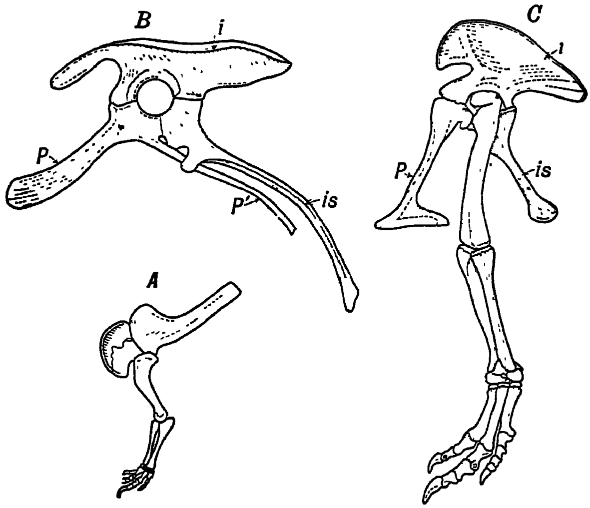

Fig. 166. — Limb and pelvis bones of the two divisions of dinosaurs. *A*, front limb, and *B*, hind limb with pelvic bones, of a carnivorous dinosaur (*Allosaurus agilis*), showing bird-like structure (Ornithischia). *C*, pelvis of a bipedal herbivorous dinosaur (*Iguanodon*), of the saurian or crocodile type (Saurischia). *i*, ilium; *is*, ischium; *p*, pubis; *p'*, post-pubic process.

ischia (bird-like ischium). Skeletal identities like these show that the dinosaurs are related to both the crocodiles and the birds. Both of these dinosaur stocks are present as early as the Middle Triassic, and their characteristic pelvic bones are illustrated above.

The earlier Saurischia were carnivorous in diet, though their descendants, the sauropods, became vegetarian. On the other hand, those with bird-like hip bones were all vegetarians. The latter are also known as the Predentata, because of a special bone developed in the front part of the jaws that is devoid of teeth.

Relation of Dinosaurs to Birds. — Besides the relationship shown in the pelvic bones as described above, the skeletons of dinosaurs

show many other similarities of structure to those of crocodiles and more especially birds. The one most often noted is that carnivorous or primitive dinosaurs have three toes as in most birds. By far the more important linkage with the birds, however, lies in the nature of the ankle joint. In mammals and living reptiles, the ankle joint is between the small bones of the ankle and the two larger ones of the lower leg. Birds and dinosaurs, on the other hand, have some of the ankle bones united with the leg bones, so that the joint comes in the middle of the ankle itself.

Dinosaur Extinction. — The dinosaurs were already well differentiated in the Upper Triassic and attained their fullness of development in the late Jurassic and on into the Cretaceous. Even toward the close of the Mesozoic most of the kinds were still present, but before the culmination of the Laramide Revolution they were all gone. The last of them are in the Lance formation, and their quickened going in North America appears to have been connected with the withdrawal of the Cretaceous inland seas during Fort Union time. Seemingly their death knell came with the obliteration of their homes in the swamps that bordered the inland seas, and the marked reduction of the climate that resulted from the rising Laramide mountains. No reptile with the dimensions and habits of dinosaurs could withstand winters, even if they were no colder than those at present in the Dismal Swamp of Virginia.

An animal stock so highly specialized as were the Cretaceous dinosaurs must have been vitally weakened and greatly reduced in numbers through the vanishing of its habitats. The cooled climates tried them sorely. Thus weakened, they were all the more easily assailed by the competing archaic mammals that began a quickened ascendancy during Lance and Fort Union times. It has been suggested that the more active, intelligent, and warm-blooded mammals fed, among other things, on dinosaur eggs and on the young dinosaurs that never had parental care.

The dinosaurian career, Lull states, "was not a brief one, for the duration of their recorded evolution was thrice that of the subsequent mammalian age. They do not represent a futile attempt on the part of nature to people the world with creatures of insignificant moment, but are comparable in majestic rise, slow culmination, and dramatic fall to the greatest nations of antiquity."

With the rise of the modern floras and their more concentrated food value, and with the passing of the dinosaurs, there came the possibility of a speedy evolution of the *archaic* mammals. These, however, because of radical defects of brain and feet and teeth,

had but a brief allotted span, and were in their turn displaced by the immigrating hordes of modernized mammals which were to be the rulers of the earth until forced to own the dominion of man.

Collateral Reading

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CHAPTER XXXV

THE JURASSIC PERIOD AND THE MANY KINDS OF REPTILES

In Europe, over the Triassic lies the widely distributed and usually but little disturbed Jurassic, a great series of strata attaining to thicknesses of over 3250 feet. The high lands that were made during the close of the Paleozoic had now vanished, and extensive epeiric seas, with a life that was astonishingly rich and varied, gradually spread over Europe. Probably as many kinds of fossils are known from Jurassic rocks alone as from all the other Mesozoic strata combined, and because of this prevalence of organic remains, these formations have been the training grounds for many European stratigraphers and paleontologists.

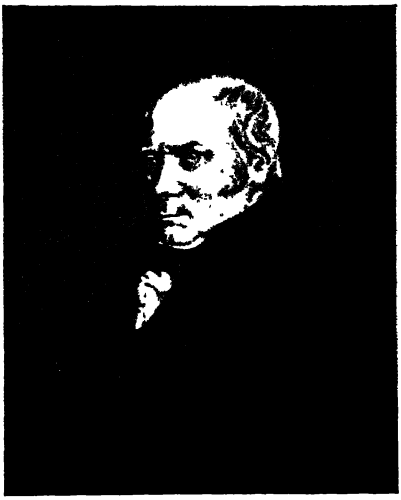

Fig. 167. — William ("Strata") Smith (1769–1839) at the age of sixty-nine. Father of English Geology and of Stratigraphy.

In general it may be said that the Jurassic was a time of crustal stability until the closing stage, when mountains were made along the Pacific border of North America and elsewhere.

The Term Jurassic.— In England, these deposits furnished fossils to William Smith, the Father of Stratigraphic Geology (Fig., above), who was the first to discern in them a value as aids in determining the age of the containing strata. In fact, it is from the Jurassic deposits of England, Germany, and France that the principles upon which Stratigraphic Geology depends have been worked out. At the beginning of the past century, Smith called this system the Oölite series, because so many of its formations abound in oölite structures, so-called from their resemblance to the roe of a fish (see Pt. I, p. 293). The earliest division he named Lias, the middle

Dogger, and the upper Malm; these are quarrymen's names for local kinds of rock and all of them are still in use, especially in England.

It is interesting to digress here a little, and to note that in the latter country the Jurassic passes through five cycles of sedimentary deposition, that is, the rocks pass five times through the cycle from arenaceous to argillaceous to calcareous strata (Geikie). At one time it was widely held that periods should be based on sedimentary cycles, but the fallacy of this conclusion is seen in that the Jurassic period has within itself five such cycles.

However, as none of the terms used by Smith were based on a definite exposure of rocks, the French geologist, Alexandre Brongniart, in 1829 proposed the name Jurassic for the system, establishing it on the equivalent formations exposed in the Jura Mountains, which lie between France and Switzerland.

Divisions of the European Jurassic. — In Germany, Von Buch, one of the great pioneers of Geology, in 1839 divided the Jurassic on the basis of rock character into Black (lower), Brown (middle), and White (upper) Jurassic, while in France Alcide d'Orbigny split it up into ten divisions. Later on Quenstedt took up a detailed study of the equivalent strata in southern Germany, in the Swabian Alps, and in 1858 divided the system into eighteen biologic zones. He was not only a good teacher, but an enthusiastic and genial man, and thus was able to enlist in his work the local collectors of fossils and even the farmers; to this day it is said that the peasants point out his divisions on their farms. Oppel, his student and successor, finally divided the Jurassic into thirty-three zones, many of which are known to have a very wide distribution. More than forty divisions are now recognized, and Buckman predicts that from eighty-five to one hundred biologic divisions (hemeræ) will eventually be defined. These facts are recited for the dual purpose of showing (1) to what degree of refinement stratigraphy may be developed when an abundance of fossils is present, and (2) that the Jurassic system has so far maintained itself as the best system for exhibiting the principles of zonal correlation.

From the studies of the abundant Jurassic marine faunas came also the first clear ideas of climatic zones in Geology and of world paleogeographic maps, through the work of Professor Neumayr of Vienna. As the result of a long study of the ammonids and their geographic distribution, he came to the conclusion in 1883 that the earth in Jurassic time had clearly marked equatorial, temperate, and cool polar climates, agreeing in the main with the present occurrences of the same zones. The consensus of opinion to-day

is that these are representative rather of faunal realms than of temperature belts. On the other hand, it is admitted that there were in the Jurassic clearly marked temperature zones.

North America, however, stands in strong contrast to the European Jurassic development, for the record is one of erosion and peneplanation over three fourths of the eastern part of this continent. It was only along the Pacific border that the ocean invaded the land and for a limited time extended east as far as Wyoming and Colorado. Probably fewer than 600 kinds of Jurassic fossils have been described from North America, while Europe has made known nearly 15,000 forms.

Outstanding Features of the Jurassic. — North America during Jurassic time remained highly emergent, continuing the geocratic conditions of the Triassic. Seas were present, for the most part, only in Mexico and along the Pacific border from California north into Alaska. For a limited time, however, there was an inland sea, a very large water-way across what is now the Rocky Mountains and the Great Plains country. This was the *Logan sea*, extending from the Arctic south into Colorado, New Mexico, and Utah. The longest enduring seas with the most prolific faunas were, however, those of Mexico and Alaska.

In Europe, Jurassic time is probably the most completely recorded of all the systems. Sea animals were not only prolific but in wonderful variety as well, the molluscs, corals, and sponges playing the greatest rôles. For the stratigrapher, the many ammonites are most significant, since their evolution led into endless variety, furnishing the criteria for detailed time divisions. In the vertebrate life of this time, marine monsters like the fish-lizards and the snake-necked reptiles dominated the seas, while the lands were ruled by dinosaurs, the most gigantic land animals that ever lived, and the air was peopled by fierce dragons and toothed birds. It was truly a most wonderful time of reptilian dominancy, but even then many kinds of archaic mammals were awaiting their chance to rise into organic supremacy.

Toward the close of the Jurassic, all along the Pacific border of North America mountains were rising and of these the Sierra Nevadas of to-day reveal in their geologic structure their past grandeur. At the same time from deep within the earth there rose into the surficial strata mighty masses of molten rocks in the form of bathyliths, that to-day are seen as the granodiorites in the highlands from Lower California into Alaska.

SUBDIVISIONS OF THE JURASSIC

Marine Phase of Europe			Alaska	American Pacific	Cordilleran	Eastern America
Upper or Malm		Purbeckian		Break		No stratigraphic record
		Portlandian	Naknek	Mariposa	Break	
		Kimmeridgian			Morrison	
		Corallian		Hinchman	Break	
		Oxfordian		tuff	Sundance	
		Callovian	Chinitna	Bicknell	Break	
Middle or Dogger				Break?		
		Bathonian	Tuxedni	Mormon-		
		Bajocian		Thompson		
Lower or Lias	Upper	Aalenian		Hardgrave		
		Toarcian				
	Middle	Charmouthian	Unnamed Lower Jurassic			
		Pliensbachian		Break		
	Lower	Sinémurian				
		Hettangian				

Jurassic Events in Eastern North America

Absence of Jurassic Deposits. — Until about 1910 it was held by many geologists that certain rather local deposits, of continental origin, occurring on the Piedmont Plateau and extending from New Jersey into Virginia, were of Jurassic age. This, the Potomac series, is now held, on the basis of its entombed plants and dinosaurs, to be of Lower Cretaceous time.

Jurassic Erosion Cycle. — In a previous chapter we saw that the Triassic period in eastern North America closed with the Palisade Disturbance, a movement that resulted in the making of block mountains probably as high as the present Sierra Nevadas. Accordingly, Jurassic time opened here with active erosion, and whatever continental deposits were formed at the time were swept into the oceanic basins. Therefore Jurassic time throughout the greater part of North America was one of erosion and without record of the sea, and the Morrison formation is the only one of fresh-water origin. All of the sediments were delivered into the Atlantic far beyond the present eastern and southern margins of the continent. This erosion cycle brought about the final transformation from the old topographic expression of high Appalachian and lower Palisade mountains to a nearly base-leveled land, and it was this peneplanation that prepared the way for the next overlap of the Atlantic Ocean, in Cretaceous time.

Potomac Disturbance. — Upwarping became pronounced toward the close of the Jurassic in Appalachis, but the uplift was restricted to the northern and western belt where the present highest elevations are still found, extending from the White Mountains southwestward into Georgia. To the east of the upwarped area, on the contrary, a downwarping took place, carrying this part of Appalachis into the depths of the Atlantic Ocean. These movements correspond to a warping or tilting about a horizontal hinge-line or axis which in a general way extended along a line drawn through the seaboard cities of Boston, New York, Philadelphia, Baltimore, Washington, and Richmond. To the west of this line, uplift increased with distance, and subsidence with distance to the east of it.

The undulating peneplain upon which the Potomac formations repose has a present slope of 112 feet per mile. The subsequent marine plain cut by the Upper Cretaceous seas has a present grade of 33 feet per mile. Therefore these two successive planes are inclined to each other at an angle of 79 feet per mile, and indicate a raising, without folding, of the western Piedmont and Appalachian areas at least several hundred feet. (Barrell 1915.)

Jurassic of the Cordilleran-Mexican Regions

Northern Pacific Border Area. — In the chapter on the Triassic it was shown that the period closed with emergence all along the entire Pacific border of North America. In consequence the sea was removed everywhere from the continent, at least from those parts of it now accessible to the geologists. This break in sedimentation lasted during the final epoch of Triassic time (Rhætic) and the early Jurassic (Lower and Middle Lias).

The Pacific Ocean again began to invade North America early in Jurassic time, sparingly in the Aleutian Peninsula, the Cook Inlet country of Alaska, and across Vancouver Island. These areas are of the British Columbic geosyncline. The widest extension at this time occurred in the Californic sea of Oregon, California, and Nevada. Of Middle Jurassic events little is as yet well known, other than that the Lower Jurassic of Alaska (1000 to 4000 feet) continues unbroken into the Middle (1500 to 2000 feet), and Upper Jurassic (5000 feet). The marine Jurassic in Alaska is the longest sequence along the Pacific border of North America, and its more than 10,000 feet of thickness consist essentially of coarse deposits, such as tuffs, conglomerates, sandstones, and shales, with lava (andesitic) flows near the top of the system. The Jurassic series in Alaska along the Pacific border is fossiliferous throughout, though by no means to the extent that is true of Europe. (See Pl., p. 505.)

Arctic Alaska. — A very thick series of continental deposits of early Upper Jurassic age has been discovered by Collier in the Cape Lisburne region of Alaska (Pl., p. 505, Map 3). The strata, which have been given the name of

the Corwin series, consist in the main of coarse deposits, shales with sandstones and some conglomerates, attaining to at least 15,000 feet in thickness, in which there are from forty to fifty low-grade non-coking *coal beds*, varying in depth from a few inches to 30 feet. Ten beds are each over 4 feet thick, and the total thickness of all the coal seen is 137 feet. The coal is of better grade than lignite. Below these coals are other workable Paleozoic non-coking coals that are of Lower Carboniferous age.

Coal beds of Middle Jurassic age are known in Mexico, California, Alaska, Greenland, Spitzbergen, Europe, Siberia, India, China, Australia, South Africa, Franz Joseph Land, and Antarctica.

Californic Sea (Walcott 1894). — The Jurassic marine deposits are widely spread over the states of California, Oregon, and Nevada (Pl., p. 505). Apparently much of Jurassic time is represented, but the detail of the formations is well known only locally, even though the much-sought-after placer gold of California originally was derived from rocks of this period, the Mariposa and Auriferous slates (Gold Belt series. See p. 510). These Upper Jurassic formations of northern California and the adjacent part of Oregon are essentially sandstones and shales, with very little of limestone and more of tuffaceous conglomerates (500 feet). In places the thickness is 2000 feet, rising to over 6000 feet elsewhere in California, and if the Lower Knoxville strata of 10,000 feet thickness, with their Jurassic flora, belong here, the maximum thickness will rise considerably above the last mentioned figure. In the Humboldt Range of Nevada there are from 1500 to 2000 feet of basal Jurassic (Liassic) limestone, followed above by 4000 feet of slates. Evidently the Upper Jurassic material was derived from a high land, and in places these formations are seen to rest unconformably on the Triassic.

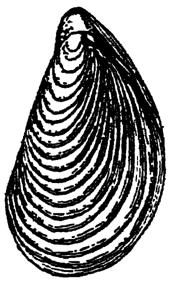

Fig. 168. — Characteristic boreal Jurassic bivalve, *Aucella pallasii.*

The faunas are always small ones and corals are locally common. During early and middle Jurassic time, the faunal migrations were from the warmer waters of the south, but in the Upper Jurassic (Mariposa, Lower Knoxville) the life was clearly of northern Pacific origin and a part of the boreal or cooler water faunas.

The Franciscan series of the Coast Ranges is probably of Jurassic age, but as to this geologists differ.

Logan Sea. — Toward the close of the Middle Jurassic, the northern Pacific, with a cool-water fauna, began to spread widely over Alaska, throughout the British Columbic geosyncline, and into the states of Montana, Idaho Wyoming, Colorado, and Utah,

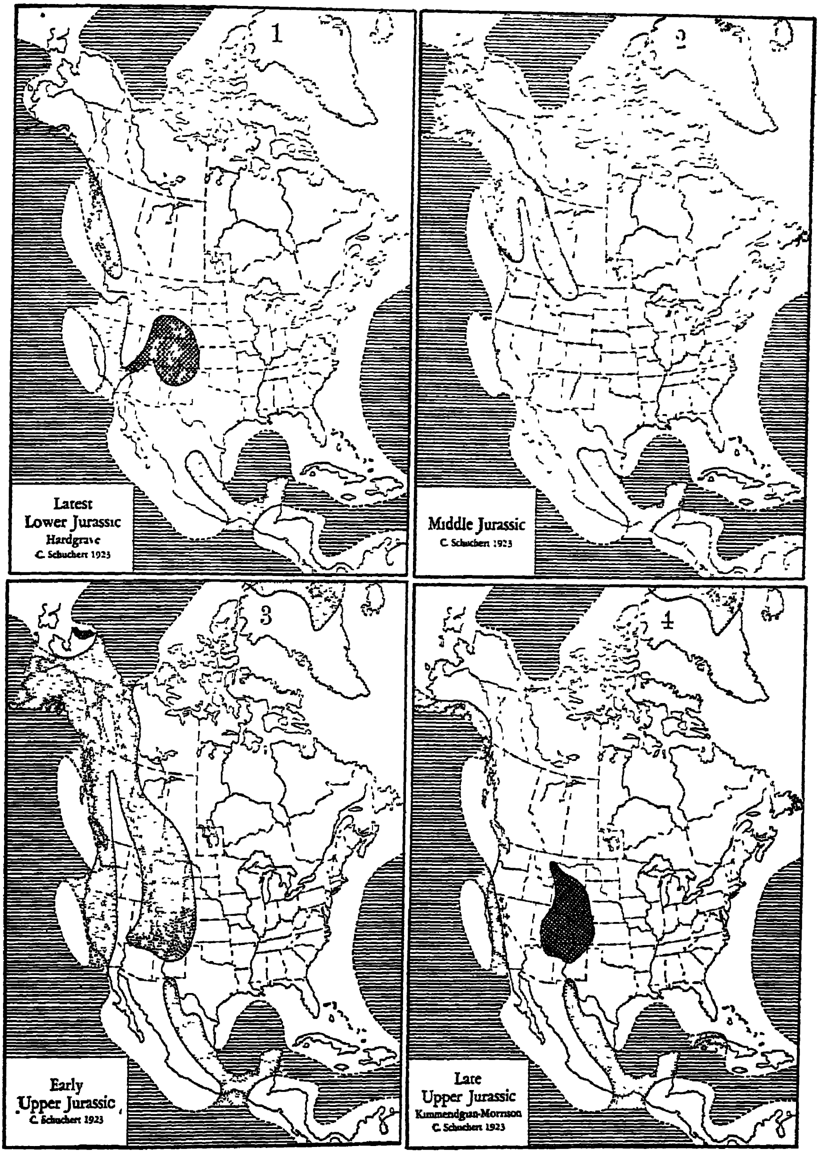

Plate 39. — Paleogeography of Jurassic time.

Epeiric seas dotted; oceans ruled. Fresh-water deposits cross-ruled. Volcanic regions indicated by crosses. See Plate 40 (p. 511) for latest Jurassic physiography. Note that the entire sedimentary record is in the western part of the continent, Central America, and Cuba. In Map 3 is shown the spread of Logan sea, with gypsum and red beds in darker shading. The highly interesting dinosaurs of the Morrison strata are found in the cross-ruled area of Map 4.

in the Rocky Mountain geosyncline (Pl., p. 505, Map 3). In the Great Plains region the deposits of Logan sea (named after W. N. Logan, who first described its extent) have an average thickness varying between 200 and 400 feet, but increasing to the west to upward of 1000 feet, and in southwestern Wyoming to 3500 feet. The nature of the deposits changes from place to place, and they consist of sandy clays, shaly marls, impure limestones, and sandstones. The cross-bedded sandstones, the changeable sediments, and the universal presence of oysters indicate that the sea was a shallow one, and further, that it flowed over a warped land eroded to a low relief.

The fauna is a small, monotonous one, probably not exceeding seventy-five species, and is almost altogether made up of Mollusca, including a few ammonids and squids. The assemblage indicates that the waters did not belong to the open sea, but were those of a large bay and of boreal origin. Among vertebrates, the common forms were the dolphin-like reptiles called ichthyosaurs (p. 517), while the plesiosaurs (p. 518) were rare. The submergence was of short duration and vanished early in the Upper Jurassic before the Alaskan waters began to abound in the boreal bivalves known as *Aucella* (Fig., p. 504).

Jurassic Deserts. — In the chapter on Triassic time, the succession of Mesozoic deserts was described, hence all that need be said here is that the red Permian and Triassic deposits of the Great Basin area are followed by thick formations (2000 feet or more) of decidedly cross-bedded sandstones of white and pink color. These are the White Cliff sandstones of the Grand Canyon region, and farther north in Utah and Colorado the Vermilion Cliff and La Plata sandstones. All appear to be older than the Morrison, and are indicative of desert conditions.

Morrison Continental Deposits. — Throughout the Great Plains country, from Montana south into New Mexico and overlying the marine Jurassic of the Logan sea, occur variegated green and red marls and shales with irregularly distributed beds of sandstone. They were first studied at Morrison near Denver, Colorado, and at Como Bluff near Medicine Bow, Wyoming. Over large areas the beds at first sight appear to be uniform in character, but seen in detail they vary considerably. The average thickness is about 200 feet, but locally it rises to over 400 feet. Because of the variability in the sediments from place to place, and especially because the strata yield in the main large dinosaurs (see Pl., p. 483, and Fig., p. 507), along with some archaic mammals (Fig., p. 516), fresh-water bivalves, snail shells, and land plants, it is apparent that they are of fresh-water origin.

Fig. 169. — Carnivorous late Jurassic (Morrison) dinosaur, *Ceratosaurus*. Length about 20 feet. Note tall tree-ferns in background, and low cycads in foreground, with an archaic mammal hiding among them. Also see page 516. After J. Smit, from Knipe's *Nebula to Man*.

Osborn has tabulated the entire Morrison life and it has 151 species. The common forms are dinosaurs (69 kinds: sauropod 31, carnivorous 13, armored 11, and iguanodont 14), archaic mammals (25), one each of bird, pterodactyl, turtle, and rhynchocephalian, crocodiles (3), fish (3), invertebrates (24) and plants (23).

Hatcher held that the Morrison deposits were laid down over a comparatively low and level plain which was occupied by small lakes connected by an interlacing system of river channels. That there were swamps in which the great dinosaurs lived and that they were occasionally entombed therein is attested by the occurrence of more or less complete skeletons preserved in the rocks. Further, there are many fresh-water clams (unionids) and snails. The topography and climatic conditions of that time may be compared to those of the region about the lower reaches of the Amazon to-day.

Ever since 1877, when dinosaurs were recognized as such for the first time in America, the age of the Morrison has been under discussion. The difficulties in correlation are great because (1) the entombed animals, while abundant, are an isolated occurrence of land forms; and (2) the local stratigraphic position is not clearly defined in the geologic sequence. The strata lie disconformably upon the earliest Upper Jurassic deposits of the Logan sea, and in the same way usually below the Cretaceous (Dakota formation). In recent years, however, Lee and Stanton have shown that the Morrison in Oklahoma and southeastern Colorado actually lies directly beneath the Upper Comanchian (Washita). This, then, according to the field relations limits its age either to Upper Jurassic or to any Comanchian time older than the upper division or Washita.

Within the past two decades giant dinosaurs have also been discovered in what was formerly German East Africa, and as the containing strata have marine beds of late Jurassic time associated with them, it is becoming clearer that the Morrison dinosaurs are in all probability also of late Jurassic age.

While the Morrison is rich in vertebrate remains, there is little that is distinctively American. The fauna is in harmony with that of Europe, and we may agree with Williston's statement that during Morrison times there was freedom of migration between the eastern and western continents, so free that nothing distinctive of either region was developed through isolation.

Mexican Geosyncline. — Through all of Paleozoic time the greater portion of Mexico was land, and formed a part of the ancient continent Columbis (Fig., p. 139). Late in the Triassic the Gulf of Mexico spread for the first time over northern Mexico. In the late Middle Jurassic, the greater part of southern and eastern Mexico and southern Texas was flooded by the Gulf and the Pacific, and we shall see further periodic floodings of this land throughout later Mesozoic time (see Pls., pp. 505, 539, 557). These seas are of the Mexican geosyncline, which endured throughout Mesozoic time and eventually became a part of the greater Gulf of Mexico. The

Jurassic sediments in the main are limestones, with but little of calcareous shales. The thickness of the formations ranges between 1000 and 2000 feet, and they abound in ammonids.

This Mexican subsidence is correlated by Burckhardt with the late Upper Jurassic. The faunas are unlike those of California and have decided European connections, since of the eighty-five ammonids described, eight are identical with those of central Europe and northern Russia, while eleven other forms are closely related. This shows that the western end of Tethys was open into the northern Atlantic and that the faunas migrated along the shores of Gondwana into Mexico. According to Buckman, there appears to be no marine Portlandian in Mexico.

Volcanic Activity. — In a previous chapter it was stated that volcanoes were active along the Pacific border of North America during Middle and early Upper Triassic time. Similar activity began again locally early in the Jurassic and continued throughout the period, becoming even more wide-spread toward its close than at any time during the Triassic (see Pl., p. 505). The eruptions were in part submarine, and in part issued from vents situated along the shore line but following in the main the distribution of the Triassic volcanoes. In these lavas, basic greenstones, that is, altered basalts, now predominate. (Lindgren.)

Nevadian Disturbance. — Toward the close of the Jurassic the Pacific System (Sierra Nevadas, the Coast Range of California, and the Humboldt Range of Nevada; also the Cascade and Klamath mountains farther north) was elevated. With the rise of these mountains to the east and west there came into existence between them the *Great Valley of California*, a narrow but long geosyncline that has persisted into the present. These mountains did not then have more than half their present height. The making of the Nevadian Mountains at this time was pointed out by Whitney in 1864 and further described by Dana. H. S. Williams (1895) and Blackwelder (1914) have called this the Nevadian movement, while Smith terms it the Cordilleran Revolution, but the deformation of the crust did not have the extent of a world-wide revolution. Although the mountains mentioned are the regions of most active deformation, it seems probable that movements more or less marked took place from Mexico into northwestern Alaska. This conclusion is drawn not only from the wide distribution of late Jurassic bathyliths, but also from the fact that at no subsequent time did the Pacific Ocean again spread over the United States so widely as it had previously done.

With the rise of the Sierra Nevadas, there also began the formation of a new trough to the east of the folded area, the *Rocky Mountain geosyncline*, of which much will be said in discussing the events

of the Cretaceous. During Lower Cretaceous time, however, this was not decidedly a sinking field.

While the Pacific border of North America was being folded, the earth-shell was also invaded by deep-seated igneous rocks (granodiorite) on a large scale. At the surface there were immense outpourings of lava, which are conspicuous in the present Sierra Nevadas. Magmas in great volume were intruded, forming the great chain of bathyliths now exposed by erosion along the Pacific border from Lower California to the Alaskan Peninsula (see Pl., p. 539). In comparison with this intrusion, all post-Proterozoic igneous phenomena fade into insignificance. The bathylith of the Sierra Nevada is 400 miles long and has a maximum width of 80 miles, while on the International Boundary there are twelve bathyliths that have a combined width of 350 miles. Farther north appears the Coast Range bathylith, probably the greatest single intrusive mass known, which extends unbroken for 1100 miles into the southern Yukon country, with a width of from 30 to 120 miles. It is thought that while these intrusions began in Middle Jurassic time, the main injections took place at the close of the period, extending into Lower Cretaceous time, and that less significant upwellings went on even to the close of the Mesozoic era. (Lindgren, and LeRoy.)

The gold-bearing veins of quartz in the rocks of the Sierra Nevadas have formed as a consequence of the upturning. The wrenching of the strata opened the leaves of the slates and also made great intersecting fissures. The opened spaces and fissures became filled with silica (quartz) deposited by the heated solutions coming from the bathyliths below, which also brought with them the ores now found in the veins. Some of these auriferous quartz veins have a width of 10 to 40 feet. Their erosion has furnished the gold found in the placers (see Pt. I, p. 431).

In the Coast Ranges of Canada the metamorphosed strata to the west of the bathyliths have silver ores and to the east of them copper ores.

Prophecy of Gondwana Break-up. — In previous chapters there was pointed out the presence since at least early Paleozoic time of Gondwana Land, a vast equatorial continent extending from Brazil across the Atlantic and Africa, and across the Indian Ocean to India. The first hint of the breaking up of this land to form the medial Atlantic and the Indian oceans came with the Jurassic, and is seen in the tremendous eruptions of volcanic rocks present in South Africa and eastern South America. The upwelling of these heavier rocks into lighter ones shows that the same condition occurred, only in greater degree, in the areas of Gondwana that have gone down into the Atlantic and Indian oceans. This breaking up of Gondwana was completed in Cretaceous time.

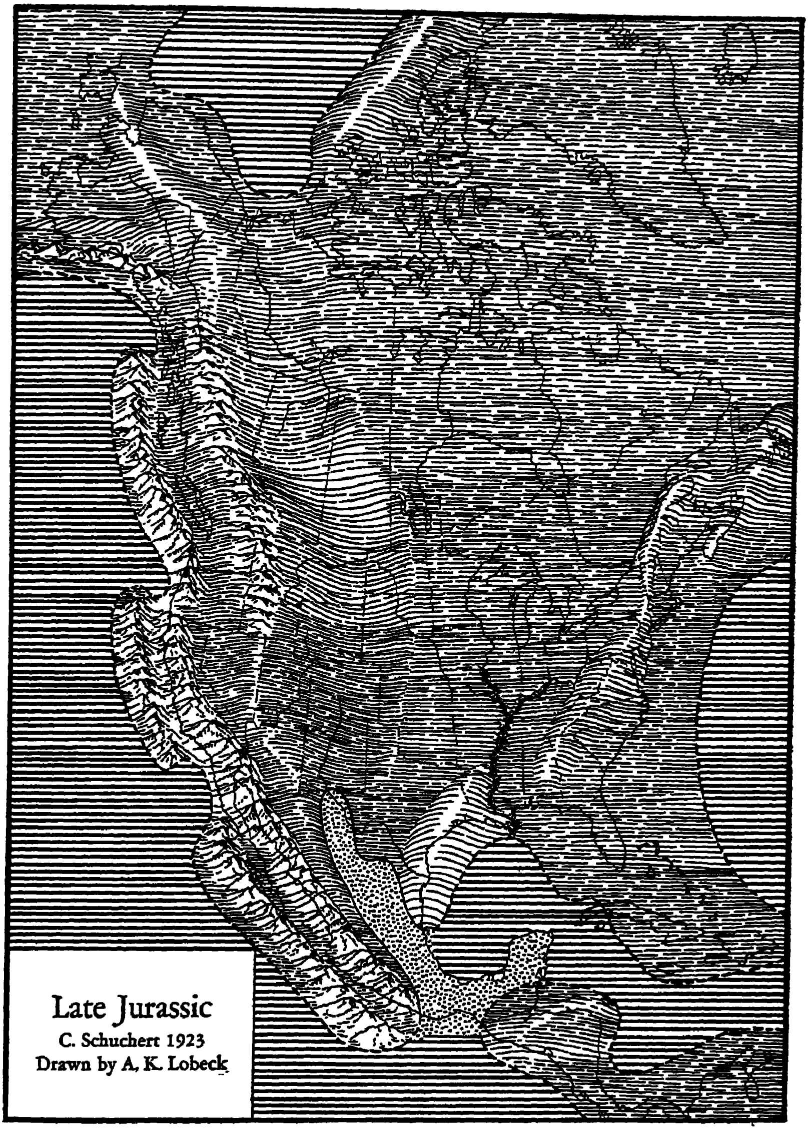

Plate 40. — Late Jurassic paleophysiography

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 39 (p. 505) for Jurassic paleogeography.

The probable geography of late Jurassic time, when the Sierra Nevadas and other mountains of the Pacific System were rising (see pp. 509–510). The Central Cordilleran ridge to the east of these mountains was rising, but is here drawn too high, while the Coloradic geosyncline is shown as too deep (pp. 546–547). Note that the Appalachians are greatly reduced (compare with the map on p. 425), and that the Mississippi drainage may have begun this early.

Over eastern South America between the Amazon, Parana, and La Plata rivers, C. L. Baker (1923) has shown that there are plateau lava flows averaging about 1000 feet in thickness, and still covering at least 300,000 square miles of land. These lavas rest upon Permian and Triassic strata, and are overlain by fresh-water sandstones thought to be of Cretaceous age. Therefore these eruptions appeared at the surface seemingly at some time during the Jurassic. Their total volume is not less than 50,000 cubic miles, a mass of the order of a great mountain range. They range from andesites and olivine-free augite-porphyrites to typical limburgites rich in olivine.

In South Africa between 26° and 33° south latitude, A. L. Du Toit has shown that the Karoo dolerites rose into the Permian and Triassic fresh-water strata at some time after the Rhætic and probably during the earlier Jurassic. The area invaded still equals 220,000 square miles and originally was not less than 330,000 square miles. These eruptives exist in numberless intrusive sheets and dikes that cut the Karoo formations so that now they look "like a mass of reinforced concrete." The total volume of the Karoo dolerites is estimated at 50,000 to 100,000 cubic miles.

Climate of Jurassic Time

We have seen that in Triassic time volcanoes and lava flows occurred in many places, and these are indicators of crustal instability. These movements do not seem to have been of sufficient magnitude to bring on a marked reduction in the climate of the world toward the close of the Triassic, and yet a cooled climate is indicated among the animals, as will be shown presently.

Students of ammonids say that the closing time of the Triassic (Rhætic) was a particularly critical one for this group. Of the more than 2600 known species of Triassic ammonids, not one continued to live into the Jurassic, and the later fullness was developed out of a single genus of Triassic time. This extinction and marked evolution along a single line seemingly point to marked environmental alterations, factors that were explained in the chapter on Triassic time.

In the Lias there are known 415 species of insects, which remind one much of modern forms. Nearly all were dwarf species, smaller than similar insects living to-day in the same latitude and far smaller than those of the earlier Paleozoic or Upper Jurassic. Handlirsch is positive that this uniform dwarfing of the Lower Jurassic insects was due to a reduction of the temperature, and that the climate was then cool and like that of present North Europe. The climate, he states, was certainly cooler than that of the Middle Triassic or of the Upper Jurassic. In confirmation of this, it may be noted that Hugh Miller in his *Old Red Sandstone* says that the fossil woods of the Cromarty Lias have the growth-rings as distinctly marked as in the pines or larches of the present forests.

With this dwarfing of the insects, and the vanishing of the late Triassic ammonids, there is also to be noted a marked quantitative reduction and geographic restriction among the reef corals of Liassic time. Not only this, but the wide distribution of reef corals in Upper Triassic times vanishes with the later cool waters of this period. We are therefore seemingly warranted in concluding that the cooling of the climate in latest Triassic and early Jurassic time was not local in character, but was rather of a wide-spread nature.

The very extensive distribution of Jurassic ammonids shows that there were at that time clearly marked temperature zones, that is, a very wide medial warm-water area, embracing the present equatorial and temperate zones, with cooler but not cold water in the polar

Fig. 170. — Two kinds of Jurassic reef-making Hexacoralla. On right, *Latomœandra seriata;* on left, *Thecosmilia trichotoma.*

areas. That the oceanic waters of Middle and Upper Jurassic times were warm throughout the greater part of the world is seen not only in the very great abundance of marine life, but also in the far northern distribution of many ammonids, corals (Fig., above), and marine reptiles. Jurassic rocks often abound in reefs made by sponges, corals, and bryozoans. Jurassic corals occur 2000 miles north of the present occurrence of similar forms. The plant distribution of Middle Jurassic time shows clearly that the floras were cosmopolitan and of a moist, warm, and probably subtropical climate. Not even in arctic lands do the fossil woods of this time show seasonal growth-rings. The insects of the early Upper Jurassic were again large and abundant, thus confirming the climatic evidence deduced from the plants. In other words, the temperature

of the early Upper Jurassic was considerably higher than it had been earlier in the period.

Evidence of Land Animals. — In the temperate and tropical belts, the world in Upper Jurassic time had the greatest of all land animals, the sauropod dinosaurs, reptiles attaining in the United States of America and in equatorial East Africa a length of about 80 feet (see Pl., p. 483, and Fig., p. 507). These animals could only have lived in a warm climate in marshes covered with succulent plants along the margins of the continents and in the estuaries of the greater rivers.

Latest Jurassic. — David White stated in 1913 that the latest Jurassic woods of England and of the United States have well developed annual rings of growth. This indicates the return of decided seasonal variations, a conclusion which is further borne out by the marked changes that take place in the floras of this time. Many of the older types, including the giant Equisetales, are blotted out, along with a marked differentiation among the Gymnosperms. Most important of all, however, is the appearance in late Jurassic time of the angiospermous flora, though its first forms are not known until early Lower Cretaceous time in New Zealand and later in the northern hemisphere. This conclusion is further supported, White says, by the rapidly developed and increased leaf expansion so characteristic of the dicotyledon, and the varied protection of the ovule with its powers of rapid maturation or of long-delayed germination. These are necessary results brought about by the long winters, followed by rapid vegetative growth and fructification within a short growing season, so as to tide over long periods of uncertainty and insure more favorable conditions for germination.

Life of the Jurassic

Land Floras. — The Middle Jurassic floras were truly cosmopolitan, and Knowlton tells us that of the North American species, excluding the cycad trunks (Fig., p. 27), about half are also found in Japan, Manchuria, Siberia, Arctic Alaska, Spitzbergen, Scandinavia, or England. What is even more remarkable, the Jurassic plants collected by the Shackleton Expedition in Louis Philippe Land, to the south of Cape Horn, in 63° south latitude, are practically the same as those of Yorkshire, England.

The flora of the Jurassic, while in the main a continuation of that of the late Triassic (see Figs., pp. 468, 507), was in every way very different from the modern ones. It consisted of rushes or Equisetales, modern herbaceous and tree ferns, cycads, gingkos, and modern conifers, the descendants of which are now found mainly in southern lands, and also shows the incoming of a number of more modern types in these groups. The cycads were of course abundant and diversified, so much so, in fact, that the Triassic

and more especially the Jurassic are often called the *Age of Cycads.* In some places, as in the state of Oaxaca, Mexico, the fossil cycads make up 72 per cent of the flora.

Medieval Insects. — While many of the stocks of modern insects are thought to have had their rise in the Triassic, this conclusion is attained only from a study of the Jurassic forms, of which about one thousand species are known, against fewer than fifty in the older period. In the Jurassic the insects began to feed on parts of the plants, but probably few as yet visited the inconspicuous flowers of that time to feed upon the pollen, and fewer still for their small amounts of honey. True butterflies and flies (Diptera) were rare in the Lias, but caddis-flies, scorpion-flies, dragon-flies, and beetles were abundant. Other kinds of insects known from this time are the cicadas, grasshoppers, locusts, cockroaches, and termites.

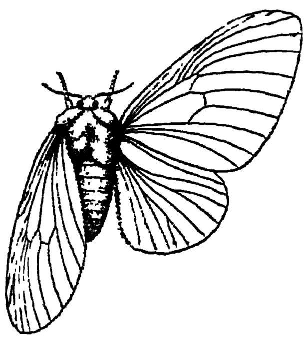

Fig. 171. — An Upper Jurassic butterfly (*Limacodites mesozoicus*), as restored by A. Handlirsch. From *Geschichte der Entomologie*, 1922.

Wheeler states that the social ants were certainly present in the early Jurassic and that they arose out of primitive wasps of the kind that now live in deserts or hot sandy places. He thinks it was the stress-climate of early Jurassic or late Triassic time that brought about their origin.

"The ants are the dominant social insects." Humanity may learn much from them, since "human and insect societies are so similar that it is difficult to detect fundamental biological differences between them." The family is the primitive basis in all societal living, and its bonds are physiological and instinctive. Each society lives in coöperative affiliation.

Social life among insects has arisen *de novo* in twenty-four different stocks, six times among beetles and fifteen times among bees, wasps, and ants. Among the white ants (termites) and ants there is even some culture, since they cultivate fungi and domesticate other insects for food, enslave members of their own or other colonies, and bequeath the farms and stocks along with their homes and hunting grounds to their succeeding generations. (W. M. Wheeler 1922.)

Land Reptiles. — In general it may be said that the reptiles attained a higher and more diversified development than in the Triassic. True lizards appeared with the Jurassic, and the turtles were then abundant and world-wide in distribution. One of the most remarkable groups of Jurassic carnivorous reptiles was that

of the flying dragons, which are described in more detail in the next chapter (see Fig., p. 523).

The dinosaurs probably attained their zenith of differentiation in the late Jurassic and then continued in fullness of development into the Lower Cretaceous. The most characteristic and largest of all were the Sauropoda (*Brontosaurus* and *Diplodocus*), and other striking large forms occurred among the carnivores (Pl., p. 485) and armored types described at length in Chapter XXXIV.

First Frogs. — It is interesting to note here that the oldest American frogs occur in the Morrison strata of Wyoming (Marsh). They were very small animals and apparently not of much significance in the animal world of their time.

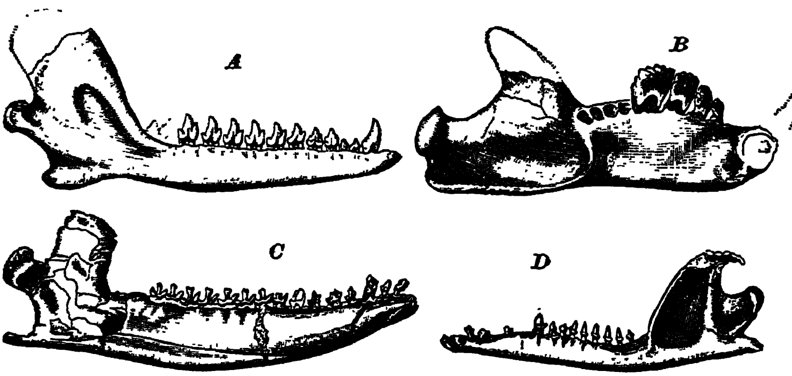

Fig. 172. — Archaic mammal jaws of the Upper Jurassic (Morrison), somewhat enlarged. After O. C. Marsh. *A, Diplocynodon. B, Ctenacodon. C, Dryolestes. D, Stylacodon.* Also see page 507.

Archaic Mammals. — The rise of the reptilian mammals was noted in the Triassic chapter, and their fragmentary bones, especially teeth and lower jaws, are met with in the various deposits of the Mesozoic. They were obscure little beasts, and none "could look a dinosaur in the face." In England they occur at the close of the Jurassic and in the Lower Cretaceous, and in America in the Morrison (Fig., above). Little is as yet known of these animals other than that the American and European species were very much alike, and that they belonged to the most primitive mammals, the Multituberculata. It is probable that the Mesozoic mammals were, in the main, egg layers.

Birds. — The oldest known fossil bird is *Archæopteryx* of the Upper Jurassic of Germany (Fig., p. 584). Two fine skeletons are known, representing a creature that in life was about the size of a modern crow. The evolution of birds is described in Chapter XL.

Reptiles of the Seas. — The *Ichthyosauria* (Greek for *fish-lizard*) were a highly characteristic group, for though they appeared in the Triassic and continued into the Cretaceous, the Jurassic, and es-

Fig. 173. — Restoration of a Jurassic marine fish-lizard (*Ichthyosaurus*). Mother with brood of young. After C. R. Knight and H. F. Osborn. Copyright, American Museum of Natural History. Also see page 475.

pecially the Lower Jurassic, was the time of their principal expansion (Fig., above). Certain localities in the Lias of England and Germany have furnished an extraordinary number of skeletons, some of the specimens preserving the embryos and impressions of the

outlines of the body and limbs and showing recognizably the nature of the skin. In their stomachs were found the hooklets of cuttle-fishes, indicating that they fed on squids, and they probably also fed on fishes. The ichthyosaurs were entirely marine in their habits; their limbs were converted into swimming paddles, and there was a dorsal fin and a large tail-fin, the latter being the principal organ of propulsion. The muzzle was drawn out into an elongated slender snout, armed with numerous sharp teeth, which were set in a continuous groove, instead of in separate sockets. The neck was very short and the skin smooth. In length, these reptiles sometimes exceeded 25 feet, and in appearance they must have been very like the modern porpoises and dolphins. The resemblance, however, is wholly superficial, since porpoises and dolphins are warm-blooded mammals.

Another group of carnivorous marine reptiles was that of the *Plesiosauria* (Greek for *near-lizard*), which appeared in the Triassic

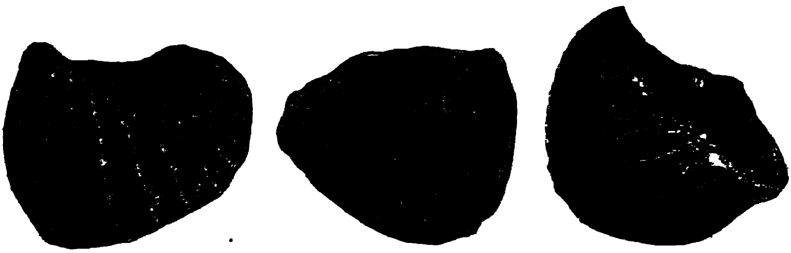

Fig. 174. — Three species of Jurassic bivalves. From left to right, *Trigonia navis*, *T. clavellata*, *T. costata*.

and culminated in the Jurassic, and which formed a curious contrast to the ichthyosaurs (Fig., p. 519). In the typical genus, *Plesiosaurus*, the head was relatively very small, and the jaws were provided with large, sharp teeth, set in distinct sockets. The neck was exceedingly long, slender, and serpent-like, and was marked off distinctly from the small, box-like body. The swimming paddles were much larger than in the ichthyosaurs and probably had more to do with locomotion. The Jurassic species of *Plesiosaurus* did not much exceed a length of 20 feet. In 1920 there was discovered in fresh-water deposits of Lower Cretaceous age (Wealden of England) a plesiosaurian 6 feet long. In this we see a Jurassic holdover and an instance of a form of marine ancestry becoming adapted to fresh-water environment.

Crocodiles swarmed in the seas and rivers of Jurassic time. In appearance these reptiles resembled the modern gavial of India and had a similar elongate and slender snout. The fore legs were much smaller than the hind, and the

Fig. 175. — Restoration of Jurassic reptiles known as plesiosaurs, from Germany. In the rear are ichthyosaurs. Also see page 517. From Fraas's Guide to the Stuttgart Museum.

animals were probably less exclusively aquatic in their habits than the present-day crocodiles and alligators.

Fishes. — Nearly all of the Paleozoic fishes were absent in the Jurassic, excepting the ganoids and lung-fishes. The former were now at their highest development, not only in the fresh waters, but in the seas as well. Some of these Jurassic forms were evidently the forerunners of modern sturgeons.

Fig. 176. — Plicated oyster of the Jurassic (*Ostrea marshi*).

The sharks of the seas had attained their modern development, and in the Jurassic the flat fishes known as rays made their appearance. The bony fishes were still rare.

Marine Invertebrates. — The seas of Jurassic time were replete with invertebrate life. This statement, however, is based on the development of Jurassic rocks in Europe and Asia, where about twenty-five forms are known for each one in America (15,000 : 600). As is pointed out elsewhere in this chapter, this dearth of marine life in America is due mainly to the absence of marine strata and to the fact that when such are present the deposits are not those of normal marine conditions.

In the Jurassic rocks, sponges are locally very common and well preserved, and in places make up thick reef limestones. Other reefs are made of modern corals (Hexacoralla) and these are of very wide distribution in the Middle and early Upper Jurassic (see Fig., p. 513). Crinids are at times common and in the Lower Jurassic are found the largest forms that ever lived, the pentacrinids, which grew to 50 feet in height, with a crown a yard in length and width. Since Jurassic times the crinids have played no important rôle in the seas. Sea-urchins of modern types are also common and here appear the so-called irregular urchins (Fig., p. 347) that later on gave rise to heart-urchins and sand-dollars.

Fig. 177. — Profile through reef-dolomite and lithographic thin-bedded limestone of a Jurassic reef or key near Solenhofen, Germany. After J. Walther.

Brachiopods are still plentiful, but not in great variety, except in the rhynchonellid and terebratulid families. Almost all of the Paleozoic forms vanish with the Jurassic. On the other hand, the rocks of Jurassic time abound in molluscs, which are prophetic of the rise of modern forms. The seas were full of small and large

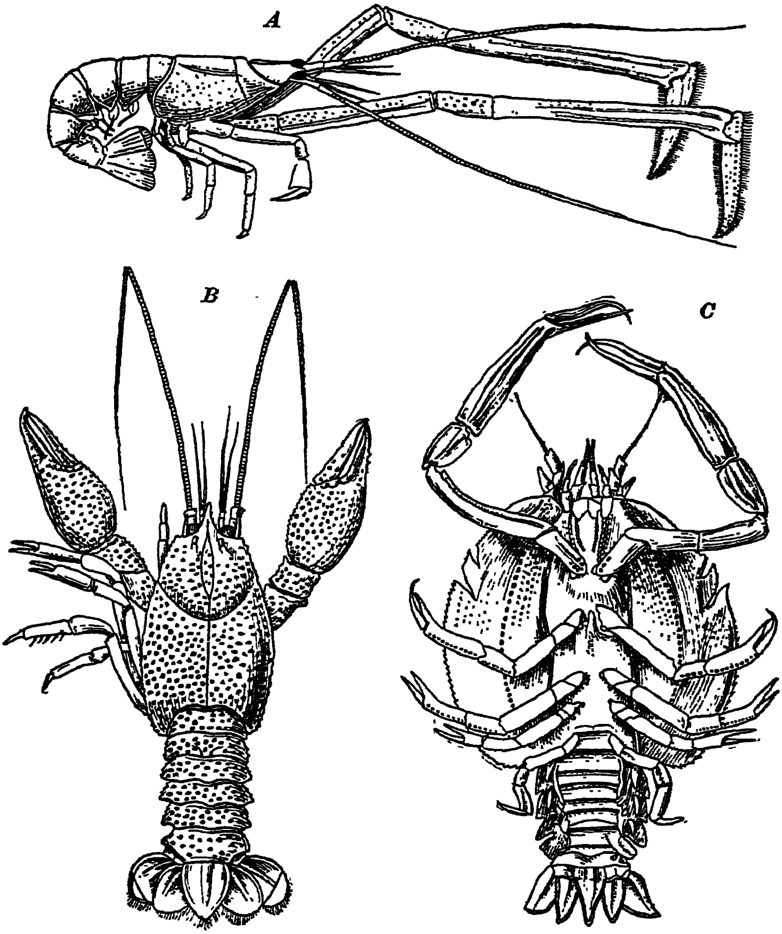

Fig. 178. — Lobsters and crabs from the Upper Jurassic reef limestones. *A*, *Mecochirus; B*, *Eryma; C*, *Eryon.* After Oppel, from Neumayr's *Erdgeschichte.*

bivalves, some of which were not only very ornate but characteristic of this time (*Trigonia*, Fig., p. 518, and plicate oysters, Fig., p. 520). Especially interesting are the many forms living in the mud. Gastropods are also common and the siphonate forms are the most valuable for historical purposes (see Pl., p. 575, Figs. 10–12).

The most characteristic shell-fish of the Jurassic, however, were the ammonids. The crustaceans, usually rare as fossils, are represented by many kinds of lobsters in the Upper Jurassic about Solenhofen, Germany, due to unusually favorable conditions of preservation. The ancestors of the modern crabs also appear here (Fig., p. 521).

Life of a Jurassic Reef. — In the region about Solenhofen, during the Upper Jurassic, a series of reefs were built by sponges and corals. On the outside of the reefs the deposits are in the main thick series of dolomites and magnesian limestone in heavy beds, while the area inside, never over 75 feet thick, consists of thin-bedded, platy limestone of very fine grain and of extraordinarily uniform character, representing a limy mud flat, in part permanently under water, and in part flooded twice daily by the tides (Fig., p. 520). These deposits are the lithographic limestones, which are used throughout the world for the engraving and etching of the monotone and colored prints known as lithographs.

In these platy limestones is found a most wonderful assemblage of animals of the sea and of the land, and even of the air, consisting of forms almost unknown elsewhere. Walther in 1904 monographed this region and its fauna, which amounts to 450 species. The life of the land is represented by a very few plants, more than 100 species of insects, probably blown upon the mud flats from the lands near by, 6 turtles, 9 crocodiles, 1 dinosaur with young, 29 flying reptiles (Pterosauria, Fig., p. 523), 3 other kinds of reptiles, and the oldest known bird (Fig., p. 584). Of fresh-water animals there are none. Of marine fishes, mainly ganoids, there are 143 species, and of crustaceans, mainly of the lobster type (Decapoda, Fig., p. 521), 71 forms; of ammonids 7, annelids 13, crinids (comatulids) 4, some starfishes, brittle-stars, and echinids, and 8 medusæ. All the other types of bottom-living invertebrates, mainly molluscs, are represented by but 40 species that were more or less accidentally drifted into the atoll.

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CHAPTER XXXVI

THE DRAGONS OF MEDIEVAL TIME

After the dinosaurs, the most extraordinary and characteristic animals of the lands during Mesozoic time were probably the dragons of the air, better known as *pterodactyls* or flying reptiles. "They must have had a grotesque resemblance to heraldic dragons" (Thomson). From the distribution of their fossil remains, it is inferred that they were common and of considerable variety, occupying the place in nature that birds do to-day. Associated with them, but far more sparingly in number and variety, were the reptilian or toothed birds. The dragons died out with the Mesozoic, but

Fig. 179. — Jurassic "dragon of the air," or pterosaur (*Rhamphorhynchus phyllurus*), × ⅒. After O. C. Marsh.

the birds went on evolving into their present wonderful adaptation. Both stocks learned to fly independently, an adaptation also invented among certain stocks of mammals and insects, and less perfectly among the fishes and amphibians. In this chapter we shall study the dragons in some detail.

Probably the most anomalous animals of Mesozoic lands were the pterodactyls or pterosaurians which laid claim to the empire of the air in those medieval times. "With outstretched pinions," says Sir Richard Owen, the great comparative anatomist, "[they] must have appeared like the soaring Roc of Arabian romance, but with the features of leathern wings with crooked claws superinduced, and gaping mouth with threatening teeth." And according to another British authority, H. G. Seeley, "The animals are as-

tonishing in their plan of construction. In aspect they are unlike birds and beasts which, in this age, hover over land and sea. They gather into themselves in the body of a single individual, structures which, at the present day, are among the most distinctive characters of certain mammals, birds, and reptiles." In brain, respiratory system, breast-bone, shoulder-girdle and the large bones of the limbs, the pterodactyls were bird-like; their skull and backbones were reptilian in construction; while the hip-bones were most like those of dinosaurs. The neck-bones were always seven in number, and in this resemble the Mammalia. In all of these characters we see the independent origins of pterodactyls and of birds in reptilian or lizard stocks.

The first pterodactyl was described in 1784 by Collini from the Upper Jurassic at Mannheim, Germany. He regarded it as an animal living in the sea, but in 1801 the great Cuvier not only correctly interpreted it as a reptile, but called it a "flying reptile." He saw also that it was one of the fingers of the hand that was very much elongated to support the wing, and accordingly gave the creature the name of pterodactyl, from the Greek words meaning *wing* and *finger.*

"There were pterodactyls as big as an albatross and that, like the albatross, sailed majestically over the sea; others, no bigger than a sparrow, fluttered merrily over the land in pursuit of insects; there were pterodactyls with long tails, pterodactyls with short tails and pterodactyls with no tails at all; and while some flew by day, others, to judge from the size of their eyes, anticipated the owls and flew by night." (Lucas 1922.)

These flying reptiles were more or less bird-like in appearance, with the front limbs modified for soaring or for flight by flapping of the wings. They flew about as well as or perhaps even better than the associated medieval birds, and as well as modern bats, which are flying mammals. On the ground they walked about readily, either on their hind legs as bipeds or on all four as quadrupeds. When at rest they probably hung themselves right side up by the clawed fingers to trees and rocks. In size, some were hardly larger than sparrows, while the average attained a wing expanse of from 2 to 3 feet across; the largest of the known ones of the Cretaceous had the extraordinary spread of 25 feet, more than twice as large as that of the condor or albatross. Even so, the skeleton was of very light construction, probably not exceeding 10 pounds in weight in the largest ones, for the large bones were hollow and filled with air in place of marrow. It is probable that even the largest of

pterodactyls did not exceed 30 pounds in live weight, and the greater number weighed less than 10 pounds; their bodies were, in fact, but an appendage to a pair of wings. Lucas states that Langley's original aëroplane required one and one half horse power for its thirty-eight pounds weight, while *Pteranodon* is estimated to have used but thirty-six thousandths of a horse power for the same purpose. Like birds, in flight pterodactyls were buoyed by internal air sacs that were in communication with the lungs, and in all probability their blood was as warm as that of birds. In most forms the tail was long, in some half the length of the entire animal, but in others it was short and even rudimentary.

The heads were usually much elongated, sometimes large and deep, or small and compact, and in some forms no larger than in sparrows; in *Pteranodon*, however (see Fig., below), the head was 45 inches long and very narrow. The brain was birdlike. The jaws were generally provided with an abundance of long, slender, pointed, and more or less curved teeth, serving for catching and holding the prey and not for mastication. In some there were cutting teeth, and the anterior part of the head appears to have been covered with a horny beak as in birds and turtles. The neck was sometimes slender as in herons, in other forms strong as in eagles. The back was always short. The skin appears to have been naked, at least nothing of scales, feathers, or hair has been seen in the wonderfully preserved pterodactyls of the Solenhofen (Germany) limestones, where twenty-nine kinds have so far been recovered. Here quite a number of specimens show in full expanse the membranes of wings and the tail rudder.

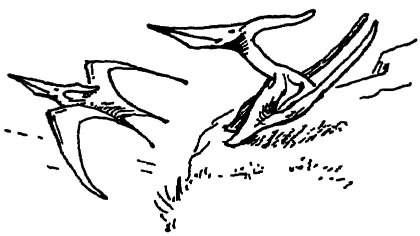

Fig. 180. — Restorations of the largest known pterodactyl (*Pteranodon*), from the Upper Cretaceous of Kansas. From the Aëronautical Journal, London.

Pterodactyls probably reproduced their kind from small eggs hatched out on the lands, as is general, though not universal, in reptiles.

Probably the most extraordinary and obvious single character of pterodactyls was the elongation and modification of the front limbs into flying organs. Not only were the larger bones of the arm and those of the hand elongated, but especially those of the fourth or wing finger. In *Pteranodon*, the wing finger attained a length of

5 feet and the wings of 8 to 12 feet. To these bones was attached the wing membrane, a very flexible leathery skin like that of bats. The inner end of this wing membrane was attached to the body, and in some forms was continued along the legs down to the ankle. A bird's wing is a series of feathers, while in pterodactyls the wing was a membrane held out by one finger, and in bats the skin is stretched between the four fingers. The hind feet had either four or five unwebbed toes, and the front limbs had four fingers, the fifth or little finger being lost.

These Mesozoic dragons appear suddenly as whole skeletons in the oldest Jurassic formations (Lias) of England and Germany, though Seeley reports scattering bones in the latest Triassic (Rhætic) of Germany and thinks he has seen bones from even older strata (Muschelkalk). Their origin therefore appears to go back to the Permian. Skeletons of pterodactyls are far more common than those of the medieval birds and occur in greatest variety in the Jurassic strata of western Europe. In America single bones of late Jurassic age (Morrison) were found by Professor Marsh of Yale in Montana and Colorado, but the group attained its maximum of size and numbers in the Cretaceous, when *Pteranodon* sailed far out over the chalk seas of Kansas (Niobrara time). Seeley states that Cope had a pterodactyl bone from the latest Cretaceous (Laramie) of the Great Plains, which, if true, shows that these extraordinary creatures died out about the same time as did the dinosaurs. During their existence the pterodactyls showed but little of evolution other than greater growth. Some twenty genera are known, fourteen in the Jurassic and about six in the Cretaceous.

The remains of pterodactyls are found more commonly in marine deposits that were laid down nearest the shore, though they are known in unmistakable fresh-water beds (Wealden and Morrison). From the marine Greensand about Cambridge, England, many thousands of their bones have been collected by quarrymen, probably fifty fair to good skeletons being known. From this we may deduce a distribution over the lands and along the seashore, though the toothless forms of Kansas have been found 200 miles offshore. They were wholly carnivorous animals, feeding upon the life of the land and sea, but there is nothing in their skeleton to show that they could swim about in the water. They may have dived after fishes as kingfishers do now, and swallowed their prey alive. It is accordingly thought they had gizzards.

The pteranodons were the organic aëroplanes of Cretaceous time and from a study of them and of soaring birds Langley obtained

hints for his invention of the first flying, or rather soaring, machine. Matthew says that *Pteranodon* was "a marvelously elaborate mechanism, gigantic in size, perfected in every detail of adaptation to its singular mode of life, automatic and precise in its response to every gust of the changing wind, to every distant flicker of light or shade that might indicate some prospect of prey or warn of a lurking enemy." They doubtless soared tirelessly across the Cretaceous seas from dawn to dusk in search of food.

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CHAPTER XXXVII

AMMONITES AND SQUIDS

Ammonites

General Characters. — The Mesozoic seas were characterized by an abundance of the shelled cephalopods known as ammonids (see Pl., p. 477, Figs. 4–16). These beautiful coiled shells, relatives of the nautilids, were exceedingly varied in size, shape, ornamentation, and in the character of their septa (the transverse plates dividing the

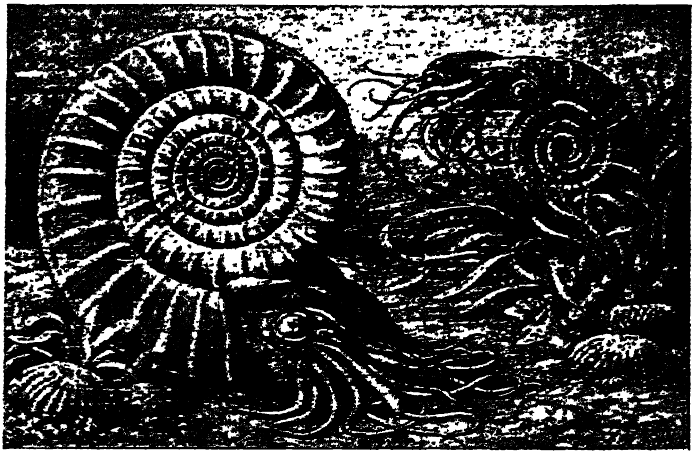

Fig. 181. — Jurassic ammonite with the animal restored. Rostrum shown in right-hand figure. From Fraas's Guide to the Stuttgart Museum.

shell cavity into chambers), and more than six thousand forms have been described by paleontologists. Probably the average size would be between 3 and 4 inches, although they may range up to diameters of 8 feet (*Pachydiscus seppenradensis* of the Upper Cretaceous of Germany), and if the coiled tube in such large ones were straightened out, the length would be between 20 and 35 feet. The ammonids therefore exceeded the Paleozoic nautilids as much in size as they did in specific differentiation. They appear to have been more active animals and better swimmers and floaters than the nautilids and therefore crawled less over the bottom of the sea. If

they were good swimmers, they must also have had a functional hyponome (see Fig., p. 226) like the nautilids. The belief that they did swim well is deduced from the nature of the very thin shells, the wide distribution of some of the species, and the small depth, or narrowness, of the coiled cones (see Fig., p. 528). This statement applies to practically all the tubes that are wound in a plane like a watch spring, but where the shells are spiral, more or less unwound, or straight, they are thicker and the animals are believed to have crawled rather than to have swum (see Pl., p. 575, Fig. 16). Such are no longer thought to be degenerates, as heretofore, but to represent new, even if reversionary, adaptations in the search for food on the sea bottoms. A few may even have been fastened to the sea bottom (*Nipponites*). Before proceeding further, the student should refresh his memory by reading what has been said about nautilids on page 225.

History of the Term. — The word *ammonite* goes back to 1732 and the days when fossils were regarded as minerals, as is indicated by the ending *ite*. The shells were so named because of a fancied resemblance to the horns of rams, pictured as one of the attributes of the Egyptian deity Ammon. In India these fossils are current as an article of trade, and they are used throughout that country in certain religious rites.

Comparison with Nautilids. — In many ways the shells of ammonids are like those of the pearly nautilus, but they differ therefrom radically in a number of respects. They are nearly always more ornate, narrower or less deep, and are often distinctly *keeled* along the center of the outer whorls. Further, the mouth of the shells often has lobed extensions on the sides (lappets), and in general there is a median keel that may be drawn out into a sharp point, the rostrum (see Fig., p. 528). On the other hand, the siphuncle in nautilids is near the center of the septa, but in the ammonids it is always placed near or in contact with the cone on its outer or ventral side (also called venter). In nautilids the mouth of the shell is never closed by an operculum, but in the goniatids and ammonids it probably was closed in most forms by a covering when the animal was at rest. This covering, when thin and made of chitin, is known as the *anaptychus*, but when thick and consisting of carbonate of lime in two hinged pieces is called the *aptychus*. The body chamber is of variable length, sometimes as long as one and a half revolutions of the shell.

Nature of Septa. — However, all of these differences, while of importance, are not so valuable in classification as is the nature of

the septa (see p. 226). In the nautilids these partitions in the chambered shell are simple and more or less concave; in the ammonids, they are simple only in the central part, and each septum becomes more and more fluted or wavy toward its junction with the outer shell (Pl., p. 477, Figs. 10 and 14). When the outer shell is absent, as is so often the case in these fossils, the *suture line*, or edge of the septa, is always seen as a wavy line with a distinct pattern, and this pattern also becomes more and more complex with age (see Fig., p. 366). It is this complicated suture line, with its intricate *lobes* (inwardly directed) and *saddles* (curved toward the mouth of the shell), that makes these fossils so valuable in deciphering the chronology of Mesozoic time, since it indicates a progressive evolution that has been determined from the sequence of the strata, checked by the individual's growth or ontogeny. The time value of the sutures was first noted by Von Buch in 1830.

The question is often asked: Why did these animals develop so complicated a type of septum? Among the nautilids we rarely see any approach to the lobed type of septum and here the living chamber is not only variously deep but wide as well. In other words, the ventral side of the cone is rounded and broad, and the shells are usually considerably deeper than those of the ammonids. Therefore the side muscles holding the shell to the animal not only have a greater holding surface in the nautilids, but, what is more important, the cone is more or less round, and therefore rests more uniformly on all parts of the animal, while in the ammonids the shells are lenticular and are therefore more easily turned to one side when in motion through the resisting water. It was probably the narrowness and the appressed nature of the shells that led to lobation of the septa, through the necessity of increasing the holding power of the animal on the shell. In any event, lobed septa are seen only in lenticular shells of cephalopods (nautilids, goniatids, ammonids).

Evolution. — The deep-shelled nautilids late in the Silurian gave rise to small and narrow-shelled *goniatids* with sparingly lobed septa. In most of the goniatids of the Devonian (Pl., p. 322, Figs. 1–6), the suture line of the lobes and saddles terminates sharply, but in the Mississippian the majority of the species not only have more lobes and saddles, but these are nearly all rounded. Thus we see a gradual change in the narrow-shelled cephalopods, beginning as true nautilids, and passing into various stocks of more or less narrow-shelled goniatids that finally gave rise in the Carboniferous to many lines of evolution among the primitive ammonids, resulting in the establishment of the latter in the warmer Permian waters of the Tethyian mediterranean (Fig., p. 431). The greatest variation among them took place during late Permian and early Triassic time. At the close of the Triassic they nearly died out, as explained

in the chapter on Triassic time. In the Jurassic, there was another rapid evolution out of one genus (*Phylloceras*), and the zenith of development was attained at this time. The waning of the ammonids began in the Lower Cretaceous, and during the Upper Cretaceous the stocks showed little of their old virility. Their complete extinction came at the close of the Cretaceous during the critical time of the Laramide Revolution.

Belemnites, Squids or Ink-fishes

General Description. — In the Mesozoic we likewise see the rise of the belemnites, the ancestors of the cuttle-fishes (also known as cuttles or squids, Fig., opposite). The word *belemnite* comes from the Greek name for *dart*, the fossils being regarded at one time as the thunder bolts of Thor, the god of thunder (Fig. *A*, p. 532). Hugh Miller relates that the country folk regarded these fossils as "of sovereign efficacy in curing bewitched cattle." The belemnids were very active, highly carnivorous cephalopods, which fed on fish, crabs, and molluscs. They had large and fully developed eyes, were devoid of external shells, and because they had but two internal gill-plumes, the name Dibranchiata has been given to them. They had ten arms, possibly eight short and two long protrusible ones, as in the living squids (Fig., opposite). In the Mesozoic these arms were often provided on their inner side with bent chitinous hooks for holding, and, more rarely, with holding suckers. Later the suckers became the dominant type. At first the belemnids had a heavy internal skeleton, but during the Mesozoic, out of the belemnid stock arose the squids, animals that continued as geologic time went on to lose more and more of the ancestral skeleton, though there is still left a vestige of it in all of the living forms. In the squids, the brain is highly specialized, and they are the highest expression of alertness among invertebrates. For this reason they have been called the "pirates of the deep."

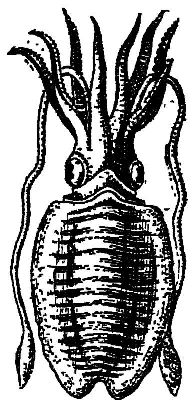

Fig. 182. — Living European ink-fish or sepia (*Sepia officinalis*), as seen from the upper side, much reduced. Note suckers on inner sides of arms. From Woodward's *Life of the Mollusca*.

Ink-sac. — All Dibranchiata are provided with an internal ink-sac containing sepia, a brown-black fluid that mixes readily with the sea-water; this the animals squirt in front of them when in danger

and then make their escape backward away from the defensive screen of colored water. The sepia of artists is a pigment made from this substance. Humboldt in his *Cosmos* (1844) says that this ink is so well preserved in Jurassic specimens that it still yields the color with which the animals' image may be drawn. Like the other cephalopods, the dibranchiates are provided with a siphon through which water is shot forward, propelling the animal backward. They can also swim by the aid of their side fins.

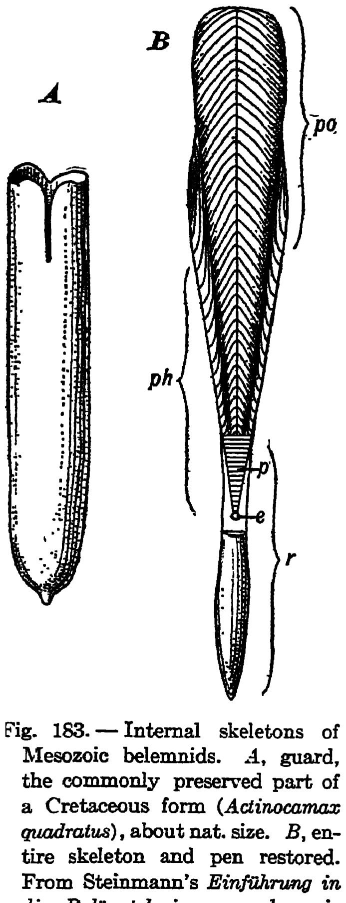

Fig. 183. — Internal skeletons of Mesozoic belemnids. *A*, guard, the commonly preserved part of a Cretaceous form (*Actinocamax quadratus*), about nat. size. *B*, entire skeleton and pen restored. From Steinmann's *Einführung in die Paläontologie*. *e*, embryonic or first shell; *p*, chambered phragmacone (vestige of an orthoceracone) passing upward into the limy or chitinous phragmacone (*ph*); *po*, proöstracum; *r*, solid guard or rostrum cut to show chambered phragmacone.

Nature of Skeleton. — The belemnids originated in the early Triassic (Pl., p. 477, Fig. 3) out of the Paleozoic orthocerids (Pl., p. 236, Fig. 19), in that the animals, as it were, made their way more and more out of the external shells and enveloped these by their mantles in such a manner that they became internal skeletons — an internal pedigree indicating their lineage (see Fig., opposite). Among the fossils the part that is usually preserved is called the *guard*, a more or less cigar-shaped, solid, calcareous body, pointed at one end, with a deep circular pit at the other. These guards are sometimes as long as 2 feet and as thick as 4 inches. In the pit of the guards and extending beyond them occurs the chambered and siphunculate *phragmacone*, the vestige of their orthocerid ancestors. This extends forward on the dorsal side into a more or less long piece, either of lime or of chitin, which is known as the *proöstracum* (see Fig. *B*, above). The belemnids are quite characteristic of the Mesozoic, are fine stratigraphic guides, and there are about four hundred kinds known, in some sixty genera.

The true squids of the Mesozoic retained only the proöstracum and a completely modified remnant of the phragmacone, which together made a thick and wide, but meshy and therefore light, secretion of carbonate of lime, known as the cuttle-bone. Over the proöstracum and projecting beyond it toward the head lay the *pen*, so called because it looks like a quill pen, made of chitin. In some of the living squids or cuttles there is left only the pen. In the Upper Jurassic of Solenhofen are found cuttle-bones fully 2 feet long, indicating animals with a probable body length of 6 to 8 feet; in the present seas live the greatest giants, whose bodies are 18 feet long, with the two protrusible arms attaining a length of 30 feet when fully extended.

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CHAPTER XXXVIII

THE LOWER CRETACEOUS, AND THE FIRST APPEARANCE OF FLOWERING PLANTS (ANGIOSPERMS)

History of the Term Cretaceous. — In the early part of the past century the European geologists regarded the rocks overlying the Jurassic and beneath the Cenozoic as making up the Cretaceous system (so named from the Latin *creta*, chalk). At first, this latter system in England and France included only deposits of chalk, of Upper Cretaceous age, but gradually more and more formations, of other materials, were added because the fossils clearly linked them together. In this way the Cretaceous came to embrace so great a mass of heterogeneous strata that with the increase of knowledge it became necessary to separate the formations into Lower and Upper Cretaceous divisions. This usage is now generally accepted in Europe. In England, the physical characters of the uppermost Lower Cretaceous and the basal Upper Cretaceous are so much alike that no break in sedimentation is readily seen, but on the Continent the separation can usually be easily made out. Moreover, the Lower Cretaceous was a rather restricted marine transgression, with widely distributed continental deposits (Wealden, and less so Neocomian, see table, p. 537), while the sediments of the Upper Cretaceous are almost wholly of marine character and probably record the most marked spreading of the oceans in all geologic time. This spreading, however, began late in the Lower Cretaceous and attained its first great extension in the Upper Cretaceous (Cenomanian and Senonian). From these facts we see that the earth underwent during the Cretaceous but one marked cycle of diastrophism. The physical evidence therefore classifies its formations into two divisions that in America are called Lower and Upper Cretaceous, though here the dividing line is not the same as in Europe.

It may be stated here that American stratigraphers are again coming to agree that their Cretaceous strata should not be divided into two independent systems of rocks or periods of time, but rather into two divisions of less import than periods. The evidence for this view is that during the last part of the Lower Cretaceous (as defined in America) or in Washita time, the Mexican sea transgressed the continent widely, spreading as far north as central Kansas and perhaps into southern Wyoming. Farther north the possible equivalent of uppermost

Washita has generally been classed as Benton or lowermost marine Upper Cretaceous. From Mexico north to central Texas the sea appears to have continued unbroken into the Upper Cretaceous (from Washita = Cenomanian into Eagle Ford or Woodbine = early Turonian).

Since the upper part and perhaps more of the Washita appears to be of the time of the European Cenomanian, which is at the base of their Upper Cretaceous, it follows that the dividing line in America between the Lower and Upper Cretaceous is not of the same time except in localities like the Rocky Mountain Province where the supposed equivalent of upper Washita lies at the base of the marine Upper Cretaceous; in Europe, this line is at the base of the Cenomanian, while in America it is at the top of the Washita formation as in the Texas-Mexico province, but this line is older than the one in the Rocky Mountain area. (See table, p. 537.)

Stanton says (1922) that the Comanchian is a good provincial series and that the term should be applied only to the Mexican sea. Its application as a series term to the Lower Cretaceous of the Pacific coast he thinks is not justified by the present state of knowledge, and the recognition of Comanchian as a system of world-wide application is still less justified.

Lower Cretaceous of Europe. — In Europe the Lower Cretaceous appears in two phases: (1) a northern shallow-water, cooler, and more or less brackish one, terminating northward and westward in continental beds (the Wealden and Neocomian); and (2) a southern normal, marine, and warmer water phase that is of wide distribution in the area of the Tethyian mediterranean. It is from this region and especially from France and Switzerland that the stratigraphic divisions are named. These are given in the table of Cretaceous formations, page 537.

Chalk Deposits. — Although chalk is not the dominant material of the Cretaceous, still, because of its conspicuous white color and its fine exposures in the cliffs along both sides of the English Channel (Anglo-Parisian basin), it gave the name to the great system of rocks following the Jurassic.

For a long time chalk was believed to be an oceanic deposit like the Globigerina oozes (see p. 72, and p. 115 of Pt. I) of the present abyssal oceans, but the kinds of fossils found in the chalks are indicative of shallow seas, and the formations are often accompanied by sands, while in closely adjacent areas the equivalent strata contain no chalk. In the Lower Cretaceous of Texas, the Kiamitia and Edwards formations have chalk associated with shallow-water deposits. In central Wyoming there is much white chalk in the Niobrara formation, but in the western part of that state deposits of the same age are sandy shales or sandstones. In central Kansas the so-called chalk deposits, the equivalent of the Niobrara, are in reality very fine yellow muds almost devoid of chalk organisms.

In central Texas the Austin chalk is also of the age of the Niobrara. In western Alabama the Selma chalk is 1000 feet thick, but of considerably younger age, and laterally it changes into marls, clays, and sands. Accordingly it is now held that the chalks are organic accumulations made in the main by the calcareous skeletons of minute pelagic plants and animals, in clear-water epeiric or shelf seas adjacent to low lands with mild climates.

White chalk is a very fine granular limestone (in the Anglo-Parisian areas 95 to 98 per cent calcium carbonate), composed in the main of entire or broken calcareous tests of floating or bottom-living Foraminifera (Fig., below) and of parts of exceedingly small floating calcareous algæ (Rhabdospheres and Coccospheres). With them are often associated many kinds of shallow-water, thick-shelled, bottom-living invertebrates, such as sea-urchins, bryozoans,

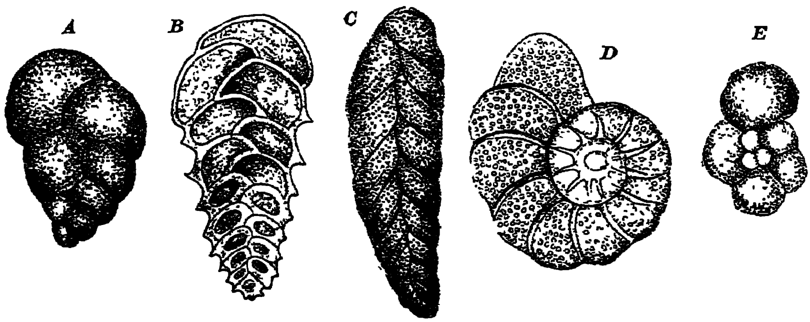

Fig. 184. — Foraminifera of the Upper Cretaceous, greatly enlarged. From Geol. Surv. of Minnesota. *A*, *B*, two species of *Textularia*. *C*, *Bolivina*. *D*, *Anomalina*. *E*, *Globigerina*.

brachiopods, and molluscs. In Europe the chalks frequently abound also in flints of different shapes and sizes, but in America these secondary alterations are rarely met with.

Significant Things about the American Lower Cretaceous. — In North America the Lower Cretaceous has two marine and independent developments, (1) in the Mexican geosyncline, extending widely over Mexico and northward across Texas into Colorado and Kansas (= *Comanchian series*); (2) a Pacific development known as the *Shastan series* of the Californic and British Columbic geosynclines. In addition there are two areas of fresh-water deposition, (3) the *Kootenai* strata of wide distribution in the Canadian Rocky Mountains and rich in coal deposits; and (4) the *Potomac* strata of limited extent along the border of the Atlantic in the United States. (See Pl., p. 539.)

TABLE OF CRETACEOUS FORMATIONS

	Europe	Atlantic Coast	Gulf Coast	Texas	Northern Great Plains	Black Hills	Central Great Plains	Colorado Plateau San Juan	Pacific Coast
	"Paleocene": Cernaysian				Greatest mt. making	Greatest mt. making	Greatest mt. making	Greatest mt. making	
					Break	Break		Break	
	Thanetian				Fort Union	Fort Union	Break	Torrejon	
						Lance: Ludlow	Denver	Puerco	
	Montian	Shark River						Break	
					Lance	Cannonball	Arapahoe	Ojo Alamo-Animas	
						Lower Lance			
	Break	Break		Gulf Series or Upper Cretaceous: Break					
							Mt. making	Mt. making	
	Danian-Maestrichtian	Manasquan		Navarro-			Laramie		
	Break	Rancocas		Escondido	Bearpaw	Montana Series: Fox Hills	Fox Hills	Kirtland	Break
								Fruitland	
			Break						
	Senonian: Campanian	Monmouth						Pictured Cliff	Upper Chico
			Ripley						
	Santonian	Matawan		Taylor	Belly River: Judith River			Lewis	
			Selma		Claggett	Pierre	Pierre	Mesaverde	
	Coniacian-Emscherian	Magothy	Eutaw		Eagle				
				Austin		Colorado: Niobrara	Niobrara		
								Mancos	
	Turonian	Break				Benton: Carlile	Carlile		
				Eagle Ford	Colorado sh.				
						Greenhorn	Greenhorn		
			Tuscaloosa						Lower Chico
						Granoros	Granoros		
	Sometimes called Middle Cretaceous: Cenomanian	Raritan	Break	Woodbine	Break?	Dakota	Dakota	Dakota	
		Break		Comanchian or Lower Cretaceous: Washita: Break			Mentor-Kiowa	Break	Break
				Denison		Break	Cheyenne		
				Fort Worth			Break		
	Gault-Albian	Potomac Series: Patapsco		Duck Creek		Fuson			Shasta Series: Horsetown
				Fredericksburg: Kiamitia					
		Break		Edwards					Break
				Comanche Pk.					
Lower Cretaceous	Lower Greensand / Upper Neocomian: Aptian			Walnut		Lakota			Knoxville
				Paluxy		Break			
	Barremian-	Arundel			Kootenai				
	Urgonian			Trinity: Glen Rose	Break				
				Travis Pk.					Break
	Wealden / ils or Lower Neocomian: Hauterivian	Break?							
	Valanginian	Patuxent							
	Berriasian	Break							

Another feature of great significance is the bowing up during Jurassic time of the central Cordilleran region from Arctic Alaska into southern Mexico and the origin of a geosyncline to the east of it that in Upper Cretaceous times becomes the Rocky Mountain or Coloradic sea. This crustal movement is but one of many in Cretaceous times, and another is the breaking down of Gondwana, the bridging land between South America and Africa, with tremendous eruptions of lavas in Brazil. The most notable facts about the Lower Cretaceous life in North America are the appearance of flowering plants, and the apparent great dearth of dinosaurs.

Mexican or Comanchian Seas

Comanchian Series. — Robert T. Hill a number of years ago made a special study of the Lower Cretaceous strata in Texas, and in 1887 he proposed for them the name *Comanche series*, because they occur in the home of the Comanche Indians. His ideas gradually prevailed and the rocks and their fossils are now being more and more widely recognized as representing a cycle of sedimentation and water movement, the Comanchian division. The succession is best known in central Texas, where there is an abundance of fossils in a thickness of 1500 feet. Hill also divided the Comanchian into three groups of formations, calling the lower *Trinity*, the middle *Fredericksburg*, and the upper *Washita*.

In central Mexico, where this grouping is not yet clearly made out, the geologists adopt a two-fold separation into Eocretaceous (Lower) and Mesocretaceous (Middle).

From southern Arkansas across central Texas into southeastern Arizona, and thence across almost all of Mexico to the Isthmus of Tehuantepec, are found limestones and marls that are of Comanchian age. These are the deposits of the most extensive inundation by the oceans which befell Mexico and which was greatest here in middle Lower Cretaceous time. Moreover, they form the greatest area of Lower Cretaceous rocks and faunas in North America (see Pl., p. 539). Aguilera of the Mexican Survey states that these deposits make up the main mass of the limestones of the folded mountains of Mexico and in this respect contrast decidedly with the sandy nature of the Shastan sediments. The average thickness is between 3300 (Mazapil) and 4000 (Vera Cruz) feet, and almost all of it is limestone (see Fig., p. 540). At Bisbee, Arizona, the thickness is about 4700 feet, beginning with conglomerates, thence passing into sandstones, shales and limestones (650 feet), and ending with red shales and variegated sandstones. In northwestern Mexico, about Hermosillo, occurs a

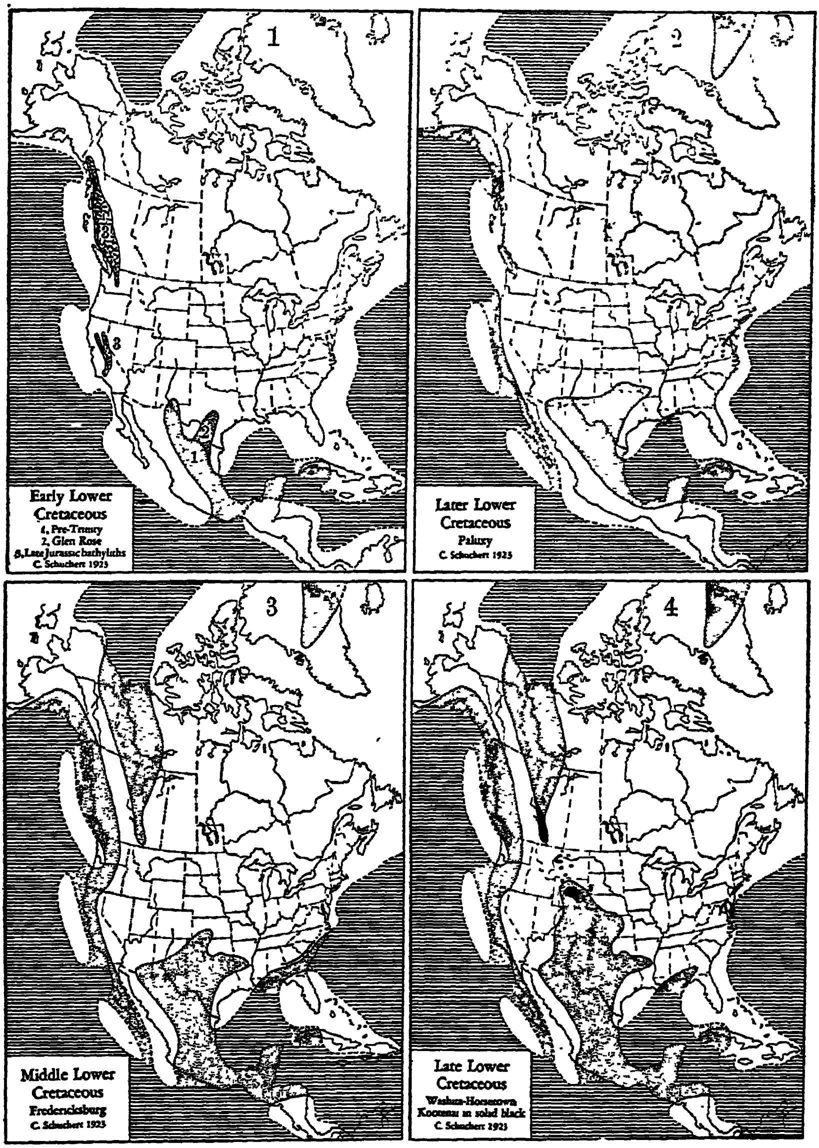

Plate 41. — Paleogeography of Lower Cretaceous time.

Epeiric and shelf seas dotted; oceans ruled. Fresh-water deposits in solid black. In Map 1 are shown the more important areas of late Jurassic igneous intrusions, and in Map 2 the beginning of the spread of Mexican waters into the greater Comanchian sea. Note in Map 2 the small areas of Potomac deposits (solid black) along the Atlantic piedmont, and in Maps 3 and 4, the Kome beds of Greenland. Note also the presence of the Cordilleran Intermontane geanticline (see p. 141).

very similar succession of strata that are nearly 3000 feet thick and bear coal in the upper beds, according to Dumble. In central Texas, the typical area for Comanchian strata, the thickness is 1500 feet, consisting of limestone, some chalk, but mainly marls and shales, thinning out to a few hundred feet of sands and marls in Arkansas. In southern Texas and Mexico the Comanchian seas are thought to go unbroken into those of Upper Cretaceous time.

Great Plains Extension of the Comanchian Sea. — Late in Comanchian time (Washita) the sea of the Texan area spread northward across New Mexico and Oklahoma, to the south and west of

Fig. 185. — Folded Comanchian limestones in Saltillo Canyon, northern Mexico. Photograph by C. B. Waite.

the Ouachita Mountains, into central eastern Kansas, and southeastern Colorado (see p. 539, Map 4). This extension did not last long and its deposits consist in the main of muds and marls with sandstones in the west and southwest. The thicknesses are usually less than a few hundred feet, which in the north and east thin down to the vanishing point. The faunas here are always limited but include oyster-like shells (*Gryphæa*, Fig., p. 541), which often abound in great quantities; evidently the waters were shallow, turbid, and more or less freshened by the rivers flowing into this extensive bay.

The flora of early Lower Cretaceous time (Trinity), as found in Texas, was still Jurassic in character. On the other hand, the plants from the top of the Lower Cretaceous (Washita) found in Kansas show that a great change had come over the forest floras, as flowering plants (Angiosperms) were now present in great numbers and in forms like those of the succeeding Cretaceous.

The marine invertebrate faunas were large and varied, consisting of about four hundred species, and were of normal marine character in Mexico and throughout Texas, becoming less so northward into Kansas and Colorado. The species were essentially of molluscs, with the ammonids making up about one third of the assemblages in Mexico and Texas, though farther north these latter are lacking more and more. Among the bivalves the most characteristic forms were the chamids *Requienia* and *Monopleura*, and the rudistids *Radiolites*, etc. (Fig., p. 542).

The Comanchian fauna as a whole is very distinct from that of the Upper Cretaceous, but the change from the Kiowa or Denison fauna to the Woodbine of

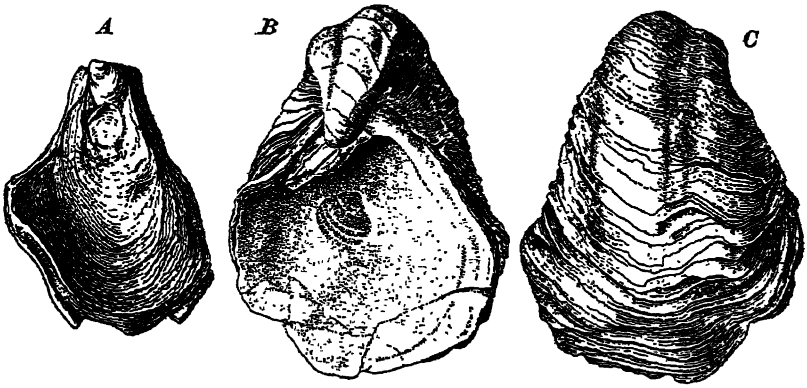

Fig. 186. — Oyster-like shells of the Comanche of Texas (*Gryphæa mucronata*). After Hill and Vaughan, U. S. Geol. Surv. *A*, upper or free valve. *B* and *C*, lower or attached valves from the inside and outside.

the Upper Cretaceous shows little if any greater contrast than is found within the divisions of the Benton. Making due allowance for differences in fauna due to littoral, deeper water, and reef facies, all of which are present in the Comanchian, this entire fauna is a unit showing only such progressive changes as are to be expected within a series (Stanton 1922).

The Comanchian faunas are also widely distributed throughout Central America, and in the high Andes in northwestern and western South America assemblages of these animals are present, though much modified by local evolution. In a general way it may be said that the Comanchian faunas were largely of mediterranean origin (Tethys), or rather that the Gulf of Mexico was in direct connection with the seas of Portugal, Spain, and southern France.

Pacific or Shastan Seas

Shastan Series of the Californic Geosyncline.—As long ago as 1869, Gabb and Whitney applied the term Shastan to the Lower Cretaceous rocks of California, recognizing correctly that the strata

"contain fossils seemingly representing ages from the Gault to the Neocomian, inclusive" (see table, p. 537). This development is wholly distinct, faunally and lithologically, from the Comanchian series.

The Nevadian Disturbance at the close of the Jurassic greatly reduced the width of the Californic geosyncline, making of it a narrow but deepened trough west of the Sierra Nevada and Klamath mountains throughout western California, but extending widely into Oregon west of the Blue Mountains. To the west of the trough lay a borderland of which the present Coast Ranges are a part. Into this subsiding trough the Shastan sea (LeConte) spread. The voluminous sediments poured into the Californic sea were coarse-

A B C

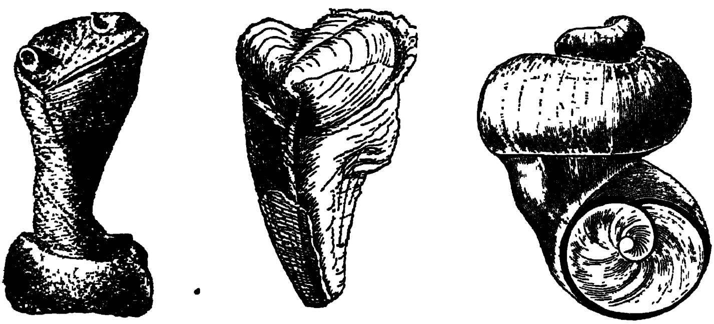

Fig. 187. — Much modified bivalves of the Comanchian. From C. A. White, U. S. Geol. Surv., and Kayser's *Lehrbuch der Geologie*. *A*, entire shell, from Texas, with the right valve attached (*Monopleura marcida*). *B*, a related form from Europe (*M. trilobita*). *C*, a form resembling a snail shell; here it is the large, spirally twisted, left valve that is attached (*Requienia ammonia*).

grained and were delivered to it by the rivers flowing out of the highlands to the eastward.

The deposits are essentially sandy shales with thin bands of sandstone, local conglomerates, and rarely thin limestones. The thickness in northern California appears to be between 9000 and 10,000 feet, of which about one third is of Knoxville time, while the remainder is of Horsetown time.

The maximum thickness of the Knoxville in northern California is about 20,000 feet, according to Diller and Stanton. Of this extraordinary thickness, about 16,000 to 17,000 feet is in general poor in fossils but occasionally there are beds replete with *Aucella* (*A. piochii*), a bivalve which is of boreal origin (see Fig., p. 504). The associated floras, however, Knowlton unhesitatingly refers to the Jurassic. (See p. 504.)

British Columbic Geosyncline. — Lower Cretaceous deposits are also known in northern Washington and along the Canadian and Alaskan coasts. The deposits of these areas are dominantly sandstones with sandy shales, and in most places include considerable thicknesses of volcanic material (from a few hundred feet up to 3350), lavas, tuffs, and ash beds. In the Queen Charlotte Islands, where these strata have coal beds, the depth is estimated at 9500 feet, and elsewhere, although somewhat less, the thicknesses are rarely as low as 2000 feet, but in places the Lower Cretaceous strata were entirely removed during the intervals of erosion. Finally, along the Arctic coast of Alaska there also appear to be Lower Cretaceous unfossiliferous strata that at Cape Lisburne are over 5000 feet thick.

The Lower Cretaceous sands and muds of the Pacific in most places overlap unconformably the older and often metamorphosed formations. This unconformity is usually a marked one, as in the Klamath Mountains and the Coast Range, or is of the erosional type. However, there are also disconformable contacts. The faunas are of the Indo-Pacific realm and are remarkably distinct throughout from those of the Comanchian seas, a condition indicating that the two provinces were completely separated from one another by a land barrier, the western Mexican mass. (See Pl., p. 539.)

The floras of the higher Knoxville (thirty-three species) and of the Horsetown (nineteen) were of the early Lower Cretaceous type (Lower Potomac), and flowering plants of the modern types (Angiosperms) are wholly unknown in them. In the Upper Knoxville (4000 feet) the small marine molluscan fauna was still of boreal origin (*Aucella crassicollis* biota). A marked change in the faunas took place in Horsetown time, as the life of the seas then had a Mediterranean (Tethys of India, also of Japan) aspect, a migration that made its appearance earliest in California and Oregon. It, too, was a molluscan fauna of about eighty species, of which over thirty forms were ammonids. This assemblage is known as the Indo-Pacific fauna. (Stanton.)

The Fresh-water Phases of Lower Cretaceous Time

Kootenai Continental Deposits. — In southern Alberta (Crowsnest Pass) and in southeastern British Columbia the Lower Cretaceous formations are of great thickness along the axis of the Rocky Mountains and are of fresh-water delta origin. These are the Kootenai deposits of the Rocky Mountain geosyncline, chiefly sandstones and sandy shales of very varied texture and appearance, and with many beds of good coal. The maximum thickness of the Kootenai is 5300 feet, with twenty-two workable coal beds, known to extend over an area of nearly 3000 square miles. To the east the Kootenai

thins rapidly to 200 feet, with two coal beds. In the Crowsnest area the coals aggregate 216 feet in thickness over an area of 230 square miles. Dowling estimates the coal of this region as equal to nearly 8,000,000,000 tons, and of this about 400,000,000 tons can be classed as anthracite.

The Kootenai is likewise present about Great Falls, Montana, where it is also coal-bearing, though the thickness here does not average over 450 feet, increasing to the west to 1500 feet, and thinning southward. The coal-bearing part of the Kootenai is represented by remnants as far south as central Wyoming. Other formations of about the same age occur in Wyoming, and in South Dakota (Lakota and Fuson formations), where about a thousand silicified cycad stumps have been found (one of which is illustrated in Fig., p. 27). The Kootenai in the Great Plains region directly overlies the Jurassic (Morrison), and may include equivalents of Lakota, Fuson, and Dakota (Lee).

Kootenai Flora. — The Kootenai fossils are essentially plants, a flora of eighty-six species being known. It is still of Jurassic character, as no flowering plants occur, the forms present consisting mainly of ferns (thirty-four species), cycads (nineteen), and conifers (twenty-five), as seen in Fig., p. 507. The flora is very similar to that in the Lower Potomac of the Atlantic border, twenty forms being common to the two areas. The botanists are disposed to regard the Kootenai flora as not younger than middle Lower Cretaceous.

Blairmore Formation. — In Cordilleran Canada the Kootenai is directly overlain by the Blairmore, 1700 feet thick, and the two are very much alike in rock characters. A conglomerate separates them, and both are of continental origin. Then in sharp contrast follow the marine Benton shales, there being no Dakota here nor in Alberta nor northern Montana. Therefore the Blairmore appears to be of Lower Cretaceous time (J. H. Sinclair 1917).

Potomac Continental Deposits. — In the chapter on Jurassic events it was stated that the mountains of eastern North America were reduced to a hilly country during that period. It is also true that the main drainage ways, the present large eastward flowing rivers, such as the Potomac, James, Roanoke, etc., were established at the same time. At the very close of the Jurassic, during the Potomac Disturbance, it seems that the strand-line of the Atlantic Ocean had been extended further to the west (see p. 503), and the continental shelf tilted a little more seaward. In other words, eastern Appalachis was fragmenting and sinking into the depths of the Atlantic Ocean. In consequence, the stream grades became more active, and the sediments eroded from the upwarped region were transported eastward to a lower level and spread as the Potomac formation upon the peneplained Piedmont Plateau (the Weverton

peneplain) of ancient crystalline rocks. These deposits of the rivers are now seen all the way from near Philadelphia, past Baltimore and Washington, through Virginia into Georgia and Alabama (see Pl., p. 539). There are also scattering exposures in the islands off New England.

The Potomac formation is best developed in Maryland, where the thickness averages between 600 and 700 feet, and all the strata have a slight dip to the southeast, averaging about 40 feet to the mile. The rocks are exposed to the east of the elevated Triassic strata, and further eastward they gradually pass beneath the later Cretaceous and Cenozoic formations. The deposits consist chiefly of unconsolidated sandy clays, which at the base and in the west have greater amounts of sands and even conglomerates, and then the materials are usually arkosic or replete with fragmented feldspars. In addition, there may be considerable amounts of clay iron-stones (siderite) in the lower part (Arundel formation), and such have been mined in Maryland for more than a century. Because of the presence of these local deposits of iron, the formations assume a red color in weathering, and in the Upper Potomac the deposits are naturally variegated (Patapsco). The Lower Potomac begins with coarse materials highly variable from place to place (Patuxent formation), and finally in the Maryland region a restricted swamp land developed, as seen in the dark and carbonaceous deposits that are even locally lignitic (Arundel). Not only this, but the roots of the forests are still in the place of their origin, and it is in these swamps that seven species of dinosaurs have been found.

The Potomac formation is clearly divisible into a lower and an upper series by a marked erosional unconformity. Further, the floras are widely dissimilar in the two parts, since the Lower Potomac (Patuxent-Arundel) still retains the Jurassic aspect, while the Upper Potomac (Patapsco) strongly introduces the Upper Cretaceous assemblage of flowering plants or Angiosperms. The Lower Potomac is wholly of fresh-water origin, and was laid down on river flood-plains over the undulating Weverton peneplain, which had a relief of about 300 feet. On the other hand, the upper Potomac, although wholly devoid of marine fossils, may be of estuarine origin; that is, it may represent the fresh-water or landward part of the various deltas facing the Atlantic Ocean.

Western Greenland. — In central western Greenland occur middle Lower Cretaceous sandstones alternating with dark shales which have locally very thin and poor beds of coal. This, the Kome formation, appears to be of fresh-water

origin, and no marine fossil is known in it. The whole series is about 700 feet thick and reposes on a rather hilly floor of ancient (Proterozoic?) crystalline rocks (see Pl., p. 539). The flora is rich in ferns (forty species), cycads (eleven), and conifers (eighteen). Of flowering plants there are seven species.

Movements toward the Close of the Lower Cretaceous

Central Cordilleran Disturbance (see Fig., below). — Along the Pacific coast from San Luis Obispo County, California, northward

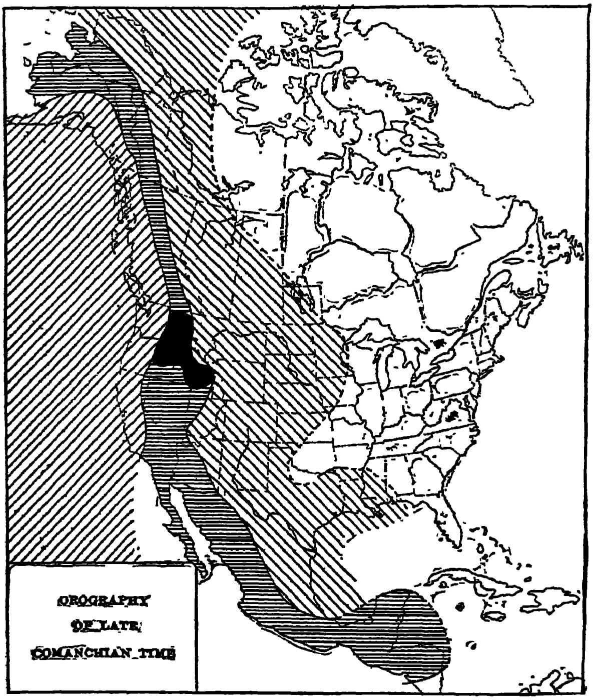

Fig. 188. — Outline map to show regions of elevation (horizontal shading and solid black), the formation of the Coloradic geosyncline (right-hand diagonal lines), and the Pacific deposits. Generalized from Ransome, *Problems of American Geology*. The black area is that of the present Columbia River Lava Plateau, the region of elevation to the north is known as the Northern Interior Plateaus, while that to the south is the Nevadan-Sonoran Region.

far into Oregon (Coast Range Mountains in wider sense), there is evidence of crustal movement during the Lower Cretaceous. Anderson states that the Knoxville is everywhere in this area penetrated and disturbed by dikes and masses of serpentine and accompanying peridotites. Moreover, in the Coast Range of southern California, where these intruded rocks occur, the Horsetown strata are also absent, while the Upper Cretaceous (Chico) unconformably overlies the older formations.

We have seen in previous chapters that the waters of the Pacific transgressed widely throughout the two western geosynclines of the North American continent during the Triassic and again in the Jurassic, and that these floods occurred mainly in the British Columbic trough. In the area of the United States, however, uplift was making itself felt as early as Middle Triassic time, apparently bowing up a low arch in western Utah, eastern Nevada, and throughout Idaho, forming together the Columbia River Plateau (black area of Fig., p. 546), and this arch persisted into late Jurassic time. At the close of the Jurassic, the Sierra Nevada folds were thrown up to the southwest of this uplift, and it was then incorporated into the area of the Nevadian Disturbance. This late Jurassic movement narrowed the former wide extension of the Californic and British Columbic geosynclines.

If we next study the paleogeography of Upper Cretaceous time it soon becomes apparent that the conditions of oceanic spreading had been further altered toward the close of the Lower Cretaceous, for subsequent to this time the Pacific geosynclines were narrow, and over what is now the site of the Rocky Mountains and far to the east in both Canada and the United States, a new inland sea appeared, the Rocky Mountain or *Coloradic sea* of Upper Cretaceous time, extending from the Gulf of Mexico into the Arctic Ocean (Fig., p. 546). The barrier that kept these waters apart was the newly bowed-up land to the west of the present main Rocky Mountain ridges, the Central Cordilleran Belt of Ransome, and this barrier continued to rise throughout all of Upper Cretaceous time. We see here therefore the beginning of the process which made the Central Cordilleran Belt of elevated plateaus extending from Arctic Alaska all the way into Central America, and it is for this reason that the movement is called the *Central Cordilleran Disturbance* (Oregonian Disturbance of Blackwelder).

This disturbance also manifested itself in Mexico, for in late Lower Cretaceous time western Mexico and Central America into Nicaragua were elevated, shutting out here more or less of the earlier Gulf of Mexico overlap.

Disruption of Gondwana (see Figs., pp. 431, 555).—The great equatorial land across the Atlantic, which had so long united northern Africa to Brazil, was broken up during Lower Cretaceous time and disappeared beneath the sea during the Upper Cretaceous. The evidence for this is at hand toward the close of the Lower Cretaceous (Gault time), when the Atlantic began to encroach upon Brazil and equatorial West Africa. Further and more extensive overlaps

were of Eocene time. We may therefore say that the present configuration of the Atlantic Ocean had its origin in earlier Cretaceous time. For other detail see the chapter on Jurassic time.

Hawaiian Islands in Cretaceous Time

In the first part of this book (p. 116) oceanic islands are described and contrasted with the continental ones. It is there shown that such islands are of volcanic origin and that they consist in the main of extruded lavas built up from the floor of the ocean. The question must now be asked, How old are oceanic islands? The Hawaiian Islands rise from a depth of 15,000 feet to the surface of the ocean, and then some of them are continued 14,000 feet higher. The present great height above sea-level is probably of very recent origin (Pleistocene) and it is held that the work of the ocean waves and the rain run-off of the islands will reduce them almost to sea-level in a short time geologically. How often such cycles have been repeated, no one knows.

The Hawaiian Islands have almost no marine deposits other than those of the present strands. Therefore to ascertain their geologic age, naturalists are dependent upon the life on the islands. This life, chiefly plants, insects, and birds, is very peculiar in that it is composed of many unrelated stocks, clearly of waif origin, drifted here by oceanic and air currents. The plants have been studied as to their original homes by F. B. H. Brown (1921), who shows that they arrived in three life waves. The oldest one, now restricted to the highlands, appears to be of Lower and Upper Cretaceous dispersal, from highland areas of Central and South America. We can therefore say that the Hawaiian Islands have certainly been in existence since early Lower Cretaceous time, and that they probably have more than once been highland areas. The second wave of organisms endured during late Eocene and Oligocene times, and its representatives are to be found in the main in the present lowlands of the islands. The third life wave was introduced by man and has been there but a few thousand years at the longest. The insects do not gainsay these conclusions and the land snails will probably eventually be found to harmonize with the evidence of the land plants.

From all these facts it appears that the oceanic islands of the Pacific are in the main old geologic structures, some of which certainly go back to the beginning of Cretaceous time. The oceans have probably always had islands and a submarine volcano can not be removed because it is subject to no marked erosive agents such as

waves and sands. On the contrary, even an inactive submarine volcano will continue to grow in elevation and circumference due to the organisms living on and about it. Bermuda in the Atlantic is a limestone island and these organic deposits, some hundreds of feet thick, cover an extinct volcano, as is shown by a deep-water well that entered the igneous rocks beneath.

Life of the Lower Cretaceous

Floras. — The floras of Lower Cretaceous time are everywhere divisible into an early and late phase of development. The older ones, Berry tells us, are those of the Jurassic retained into Cretaceous time, and they consist of ferns, cycads, and conifers (see Figs., pp. 468 and 507). The rushes, however, had now dwindled into their present meagre representation, and the older Mesozoic ferns were giving way to the modern ones. Finally, in late Lower Cretaceous time, the cycads also began to wane, and their places were taken by the flowering plants or Angiosperms which were increasing in importance, for one third of these floras were of this type. They were the ancestors of the modern floras and prophetic of the rise of the living forests. In fact, at least three of the genera are still living (*Sassafras*, *Populus*, *Celastrophyllum*). Between three and four hundred species of Lower Cretaceous plants are known in America, and of these about two thirds are of the older development. Before the close of the Lower Cretaceous this early hardwood forest of modern appearance had spread to Alaska, Greenland, and Portugal, where elms, oaks, maples, and magnolias occurred, and later in the earliest Upper Cretaceous times it spread over the entire world.

Angiosperms. — The Angiosperms or modern plants have dominated the plant kingdom since the early Upper Cretaceous. *Their advent was as important in the plant world as was that of man among the animals.* Their second modernization came early in the Eocene, and a third one in the cooled climates of Miocene time. Far more than 100,000 species are now living, more than of all other plants put together. Angiosperms are not only the highest plants structurally, but also the most diversified and widely spread, and the most adaptable to every kind of condition. They live in all climates and at all altitudes in which plants can exist, and make forests, prairies, and meadows. "Ranging in size from tiny aquatics to giant trees several hundred feet tall, and ranging in their life span from that of a single season to several thousand years, they are the most impressive members of the vegetable kingdom" (Berry). At first

the Angiosperms were all tree-like or woody, the herbaceous ones being of relatively modern origin.

Fruits are confined almost exclusively to Angiosperms, and their variety is almost as great as that of flowers. These fruits are of prime value to many animals and especially to humanity. It seems more than a coincidence that Angiosperms should have arisen and become world-wide in dispersal before the widest deployment and most significant evolution of the mammals took place. Berry is correct in believing that human civilization could not have evolved but for the presence of this group of plants.

The most important single structure of the Angiosperms is their reproductive organs, the beautiful flowers. Their brightness of color and sweetness of scent bring insects and birds to them to suck their nectar and at the same time to cross-fertilize them. The parts of Angiosperm flowers are remarkably constant. On the outside is the floral envelope consisting of calyx and corolla, the latter being commonly composed of petals. Within are the stamens and at the center of the flower is the pistil containing the seeds.

The term Angiosperm has reference to the fact that the ovaries are closed, a condition found in no other plants. This is a protective device for the seeds while ripening, and the covering also helps later on in their dispersal and germination. Furthermore, the Angiosperm seeds have much nutriment stored in them, to make more certain the growth of the embryo. To fertilize the seeds in the ovaries, however, the pollen grains held on the sticky stigma surmounting the pistil must grow down through it until they enter the seeds.

In Angiosperms the woody or vascular system is the best developed conductive tissue and supporting skeleton of any among the plants, and enables them all the better to store the nutritive materials. In addition, the large leaf surfaces lead to increased production of these materials.

Origin of Flowering Plants. — Where the Angiosperms or flowering plants originated is not yet known. In Lower Cretaceous times they arrive in North America, Greenland, and Portugal "ready made," as it were, and give no proof as yet as to their ancestry.

In 1917 came the surprising news that a genuine and even specialized flowering plant (*Artocarpidium*) had been discovered in the older part of the Lower Cretaceous of New Zealand (E. A. N. Arber). This clearly indicates that these plants had attained a world-wide distribution in the earlier half of Cretaceous time, that the stock is older than is generally believed, and that it may

Fig. 189. — View in the Royal Museum at Brussels, Belgium, showing nine mounted skeletons of the herbivorous Lower Cretaceous dinosaur *Iguanodon* (*I. bernissartensis*). See page 552. From a photograph furnished by Professor Dollo.

have originated in a cool climate during Jurassic or even Triassic time.

Sinnott and Bailey (1914–1915) hold that the Angiosperms arose in upland floras living in cool climates, certainly as early as the Jurassic and possibly even in the Permian; and that they originated from a palmate coniferous rather than from a pinnate cycadean stock. Wieland, on the other hand, holds that the Angiosperms arose out of a cycadaceous stock. J. H. Hoskins in 1923 announced the discovery of monocotyledonous wood in the Pennsylvanian (Conemaughan) of Illinois, but other botanists reject his conclusion.

Woody Angiosperms were the first of the flowering plants to arise. Of these trees and shrubs there are living to-day about 4200 genera, and of herbs only 2600 genera. The annual herbs, Sinnott says, arose out of perennial woody forms, and their reduction was due either to winters or droughts, giving rise to rhizomes in the ground, or better still, to the annual production of seeds. Herbs can best adapt themselves to a cold climate by living over the period of low temperature under ground, or in the form of seeds.

It is also probable that the flowers of Angiosperms arose independently of insect pollenation, and that for a long time fructification took place through the aid of the wind. That flowers were visited by insects during the Lower Cretaceous, and that they then fed upon the pollen is probable, but the interdependence of flowering plants and insects so highly perfected to-day is a development that probably arose in Cretaceous time (J. J. Lovell 1917).

Dinosaurs. — Almost nothing is known of the Lower Cretaceous dinosaurs of North America other than the fragmentary skeletons of the Potomac formation, described by Lull, but in Europe they are often present in the Wealden and equivalent formations.

A most interesting burial of plant-feeding, bipedal, Lower Cretaceous dinosaurs has been found in the coal mines near Bernissart, Belgium. These are known as *Iguanodon* and the genus had long been known from single bones found in the Wealden of Europe. In taking out coal the miners came upon a river channel deposit cutting the coal, and in this, over 1000 feet beneath the surface, were twenty-two complete and seven incomplete animals (Fig., p. 551).

Marine Life. — The ammonids were still plentiful, though less so than in the Jurassic, but began to show a great loss of vitality, in that but few new stocks arose. For other details see Chapter XXXVII. The belemnids were still abundant and flourishing.

The other invertebrate life of the sea was not very different from that of the Jurassic, and only a few of the more marked changes need be noted. The sea-urchins were very varied and prolific in the warmer seas, and the heart-urchins (irregular types) here and in the Upper Cretaceous attained their climax of evolution (see Fig., p. 347). Among the bivalves, the ribbed oysters (Fig., p. 520) and the oyster-like Gryphæas (Fig., p. 541) were very abundant, especially in Tethys.

In the boreal seas, the aucellids (Fig., p. 504) were still plentiful, while in the equatorial waters of Europe, Texas, and Central America there arose remarkably aberrant stocks of bivalves, in which one valve was cemented to some object, the shell growing upward into a short or long, twisted, thick cone, while the covering valve was either twisted or a thickened and simple hood (Fig., p. 542). These were the chamids and rudistids, which also continued into the Upper Cretaceous and there gave rise to the caprinids and larger rudistids, shells that were veritable reef-builders.

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CHAPTER XXXIX

UPPER CRETACEOUS TIME AND THE BIRTH OF THE ROCKY MOUNTAINS

The Upper Cretaceous strata were the last to be formed in the Mesozoic era. The way in which the Cretaceous system received its name from the chalk has been dealt with in the chapter on the Lower Cretaceous.

Significant Things About the Upper Cretaceous. — Upper Cretaceous time is known not only for its widely spread chalk deposits but as well for the great flooding of the continents by the oceans. Suess (see Fig., opposite) was the first to point out this flood, probably the greatest of all those of geologic time. In North America was developed the vast Rocky Mountain or Coloradic epeiric sea (see Fig., p. 555).

Fig. 190. — Eduard Suess (1831–1914), author of the monumental treatise, *The Face of the Earth.*

The next most striking fact is the extraordinary amount of mountain making that took place toward the close of the Cretaceous, since the Rockies then arose in North America and the Andes in South America. As a result of this orogeny, the climate was cooled, but there was no widespread glacial one, as might have been expected, although late Cretaceous tillites have been discovered in Australia. The origination of the Gulf of Mexico out of the southern continuation of the Appalachic geosyncline and the definite appearance of Antillis are of this time, and also the formation of the Indian Ocean. With the foundering of parts of the lands bounding the ancestral Indian Ocean, came the mightiest lava floods of all time, to be seen in India, Arabia, and Africa.

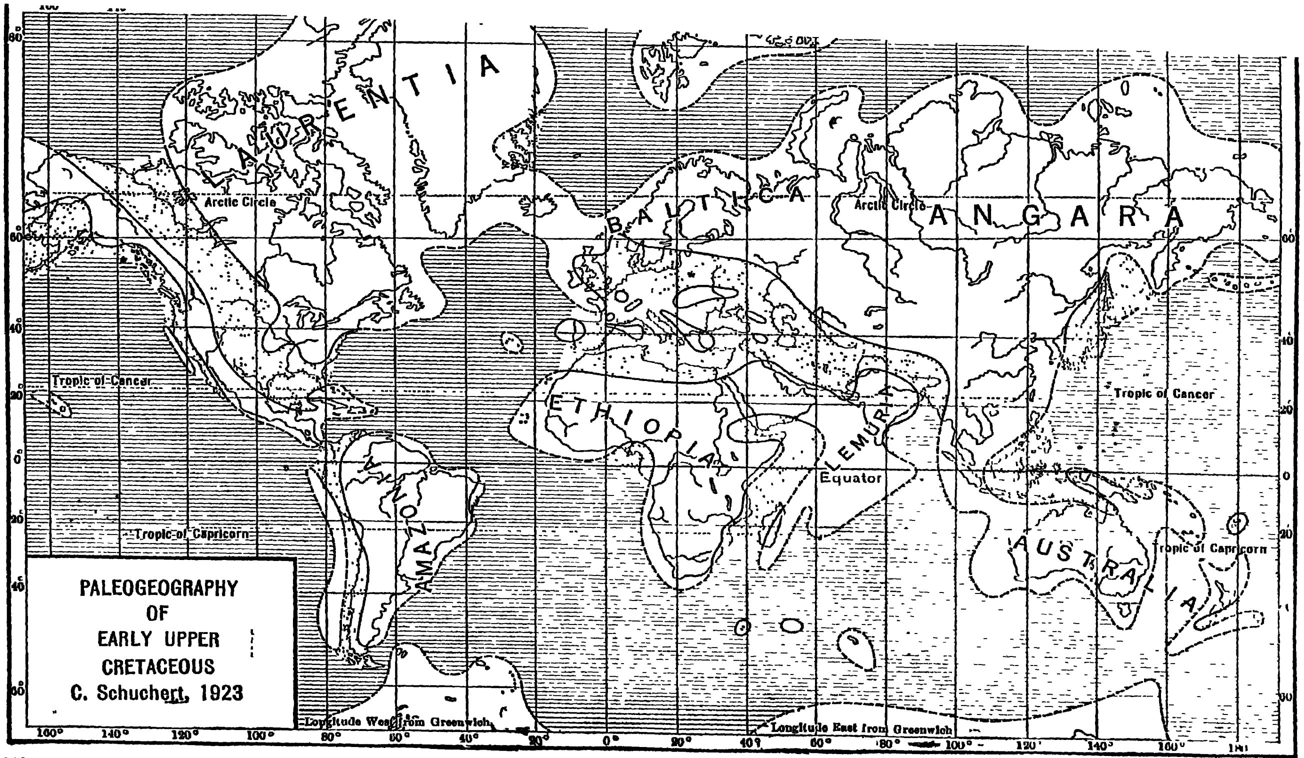

Fig. 191. — The great Middle Cretaceous transgression (dotted) of the oceans (ruled) over the lands. The time is upper Benton or Turonian. This was probably the greatest submergence that ever befell the continents. Laurentia, Baltica, and Angara make the Holarctic continent also known as Eria.

The Upper Cretaceous was the second marked time of coal making in North America and all of its coal was laid down west of the Mississippi valley (see Fig., p. 402).

All through the latter part of the Cretaceous there was a dying out of marine and land animals, and the complete blotting out of the ammonids, belemnids, dragons, dinosaurs, and birds with teeth. The scaled marine reptiles appeared with the Cretaceous and died out with it. The medieval or Mesozoic era had come to an end.

For the succession of Upper Cretaceous formations see the table on page 537.

Part I. Seas and Strata

The Great Inland Seas of North America

During Upper Cretaceous time a more or less large inland sea was in existence which at first extended from the Arctic Ocean into southern Mexico and from the Cordilleran highlands east almost to the Mississippi River. To the west lay the Central Cordilleran highlands described in the previous chapter and these furnished nearly all the sediments for the seas to the east of them. All of that portion to the north of Texas is known as the *Coloradic sea,* taking its name not only from the state of Colorado where the Upper Cretaceous formations are well developed, but as well from the older deposits comprehended under the term Colorado series. It is also known as the Rocky Mountain epeiric sea. During this time the sea had its greatest extension, and its deposits continued unbroken into the younger Montana series, though the seaways were then smaller and finally vanished entirely and for all time. South of New Mexico the Coloradic sea continued widely into the *Mexican sea* that covered the eastern half of Mexico all the way south to Tehuantepec. Northeastward these waters were continuous with the *Gulf of Mexico overlap* of the southern United States. Study maps on page 557.

It has been established that the Lower Cretaceous sea appeared first in southern Mexico and that it was an extension of the Gulf of Mexico. In the course of this time the Mexican sea spread farther and farther to the north, finally attaining Kansas and Colorado, while in the far north the Arctic Ocean began to spread southward toward the close of Lower Cretaceous time. Then the southern flood is believed to have begun oscillating back and forth across Kansas and southeastern Colorado. Until recently it was therefore held that there was a long dry-land interval between the Lower and Upper Cretaceous, but Stanton in a recent study of this problem (1922) holds that the muds and sands of Washita time (Cheyenne,

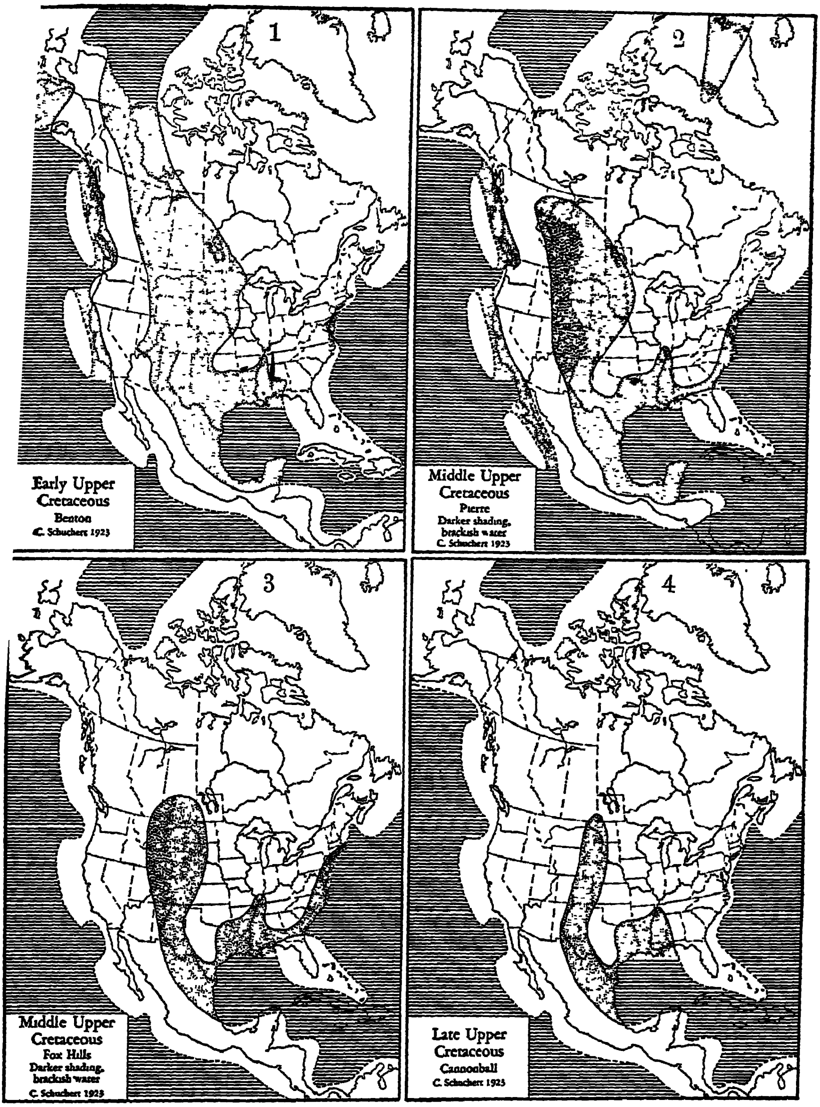

Plate 42. — Paleogeography of Upper Cretaceous time.

Epeiric and shelf seas dotted; oceans ruled. Fresh-water deposits in solid black. See Plate 43 (p. 569) for latest Cretaceous physiography.

In Map 1 note the vast Coloradic sea, and in the other maps its retreat toward the south. The darker shading in Maps 2 and 3 marks the area of the thick brackish-water deposits which come from the rising Cordilleran Intermontane geanticline. Note also the submergence of Antillis and the continuous land bridge between North and South America.

Kiowa, Mentor) represent "merely a halt in that advance rather than a complete retreat of the sea from the Great Plains area as far south as Texas." Accordingly, as pointed out in the preceding chapter, there is no proper boundary distinguishing the two divisions, i.e., between the Lower Cretaceous (Comanchian) and Upper Cretaceous.

Shortly after the Washita, perhaps in middle Dakota time, the Coloradic sea was continuous into the Arctic Ocean and a little later in Benton time had its greatest eastward extension into Iowa, Minnesota, and Manitoba. In the Mexico-Texas portion of the great inland sea, limestones and chalks are the dominant strata, and

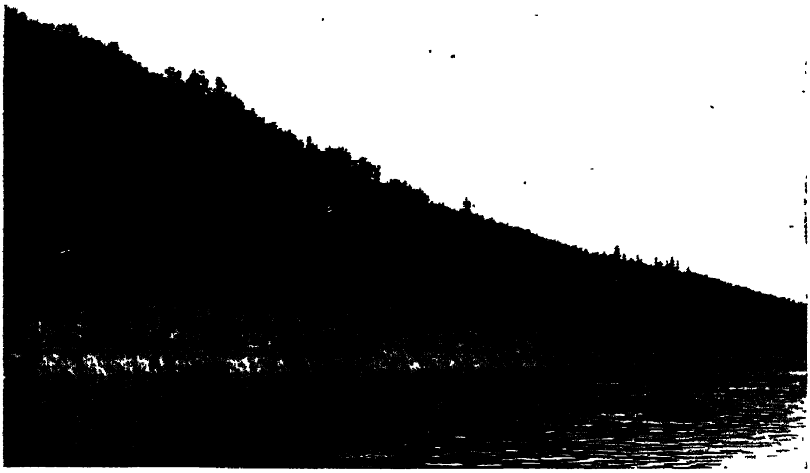

Fig. 192. — Conformable contact of Upper Cretaceous shales on Devonian limestones near Fort McMurray, Athabasca River, Alberta. The contact is just above the vertical cliff. Photograph by E. M. Kindle, Geol. Surv. Canada.

elsewhere occur muds and sands with coal beds. However, the time of most extensive chalk making was just before the middle of the Upper Cretaceous in the Niobrara, when this kind of rock was laid down from Manitoba south into Texas.

Dakota Formation. — The Dakota sandstone was originally studied "back of the town of Dakota, Nebraska" on the Missouri River about 6 miles south of Sioux City, Iowa. Here the thickness in wells is from 350 to 400 feet, and near the top are found unmistakable Upper Cretaceous brackish-water or marine shells. For a time the whole of this sandstone was believed to form the invading base of the Upper Cretaceous throughout the area of the Great Plains. To the north of the Black Hills there appears to be no typical Dakota sandstone, and southward from Wyoming the basal Cretaceous sandstones and shales also em-

Fig. 193. — Restorations of vertebrates of the Chalk seas of Kansas. The long-necked reptile attacking the wingless reptilian bird (*Hesperornis*) is a plesiosaur (*Elasmosaurus*); the flying reptiles on the left are dragons or pterosaurs (*Pteranodon*); on the right is a fish-lizard (*Ichthyosaurus*), attacking winged reptilian birds (*Ichthyornis*). After Williston. From University of Chicago Press.

brace Comanchian fossils. The entire distribution of these sandstones has been discussed by Stanton (1922) and the flora has been presented in part by Berry (1922).

Formations of the Great Inland Seas. — The deposits of the Coloradic sea are very variable from place to place, and while in the main made up of muds and sands, there are areas of chalk and limestone deposits (Niobrara and Austin formations, 200 to 1500 feet thick). In general, the formations are thickest in the west, where the materials came from the periodically rising Rocky Mountains, so that brackish and even fresh-water deposits are more frequent here than in the eastern part of the Coloradic sea. For this reason the greater amount of coal (bituminous and lignite) occurs in the western areas of this seaway. While the coal marshes were of greatest extent toward the close of the Cretaceous, some coal was laid down in various places throughout this period, evidence which indicates that the sea was shallow, with many deltas in the western area, along with bars and marshy islands, ever changing from place to place, due to the shifting sea currents, the unloading rivers, and the crustal warpings. Finally, the entire Coloradic basin was silted full, and with the final decided elevation of the Rocky Mountains, this epeiric sea vanished.

In Iowa and Minnesota the Upper Cretaceous deposits are thin, ranging from less than 100 feet to 500 feet, and embracing only the older half of the deposits. Westward the formations thicken rapidly, and the rate of deposition increases with time, so that in South Dakota and northwestern Nebraska the depth of the strata is about 4000 feet. In northern central Wyoming and the Great Plains in general, the thickness is about 10,000 feet, and finally in southwestern Wyoming the sections range from 13,000 to over 20,000 feet. These great thicknesses lie in the deepest western part of the basin, and in a general way it can be said that the deposits thin out irregularly both to the north and to the south, though there are notable exceptions to this, as in southwestern Colorado, where the maximum depth is given as less than 7000 feet. In the Big Horn coal basin of Alberta, the thicknesses are also considerable, being about 6200 feet, and this depth is maintained northward into the Saskatchewan country. Still farther north the depths are greatly reduced.

Toward the close of the Cretaceous (Laramie-Lance) nearly all of the sea-ways changed from marine to fresh-water conditions, and the sediments were coarse materials (sandstones), often derived from lavas (largely andesites), and ranging in thickness up to 6500 feet. However, at intervals the sea reappeared for a short time through-

out the area of the Great Plains, depositing beds a few feet in thickness made up almost entirely of oyster shells. These oscillations of the sea and the general vanishing of the marine waters are prophetic of the coming Laramide Revolution.

The faunas of the Coloradic sea were made up almost entirely of molluscs, of which the bivalves (*Inoceramus*, with a length of 3.5 feet) and gastropods had the greatest specific development, while the ammonids, although greatly reduced in numbers, are still most significant in determining the geologic age of the strata (see Pl., p. 575). Corals, sea-urchins, and brachiopods, so common in Europe, are almost unknown in deposits of this sea north of Texas. The Coloradic faunas have their own aspect, with the greatest number of species in common with the Mexican sea and the least with the Atlantic overlap.

Fig. 194. — Projecting ledges of Eocene (Midway) limestone of the Cenozoic resting on Cretaceous shale (Escondido) at White Bluff, Rio Grande, Texas. Note the conformable contact. Photograph by L. W. Stephenson, U. S. Geol. Surv.

Formations of the Mexican Sea. — The great inland sea described in the previous pages continued widely into Mexico, where it opened out into the Gulf. The overlap came from the Gulf of Mexico and extended all the way from central Mexico across the Gulf States northeastward to unite finally with the shelf seas of the Atlantic Ocean. In this spreading we see clearly for the first time the appearance of the Gulf of Mexico, but as a greater gulf than it is now.

In southern Texas on the border line of Mexico (Eagle Pass), Upper Cretaceous time is fully represented and there are here about 6550 feet of strata that in the lower portion are made up of clays, marls, chalk, and chalky limestones (the Austin chalks and limestones are 1500 feet thick), while the upper 4000 feet consist largely of sandstones and clays, with valuable coal beds, which recur in the state of Coahuila (see Cretaceous-Eocene contact, Fig., p. 561). The Upper Cretaceous is also well developed throughout northeastern Mexico and as far south as San Luis Potosi in central Mexico, where the Cardenas limestones have an estimated thickness of 1800 feet. South of this region the formations gradually vanish, and none are known in southern Mexico and the greater part of Central America.

Western Gulf Border. — The Gulf of Mexico in Upper Cretaceous times also spread widely over the Gulf States from Texas to Georgia (see Pl., p. 557). The overlap appeared earliest in Texas in harmony with the early origin of the Coloradic sea, and did not begin to spread actual marine deposits east of the Mississippi River until the second half of Upper Cretaceous time (Montana). We have seen that the Upper Cretaceous in southern Texas (Eagle Pass) has a thickness of about 6550 feet, thinning to about 4000 feet in the northeastern part of the state, where the whole of this period is represented by marine beds. Farther east in Arkansas the shore phase of the system is thin, and only the Upper Cretaceous is present, but in Louisiana beneath the Cenozoic overlap probably all of the strata are present.

Eastern Gulf Border. — The trough of the Mississippi River is occupied by rocks younger than the Mesozoic, and therefore nothing of these strata is seen except in extreme western Tennessee and southern Illinois. Here on the higher eastern land of the trough, Upper Cretaceous formations that are practically unconsolidated are met with from Tennessee through eastern Mississippi into Alabama and Georgia. Nearly everywhere they overlap Paleozoic strata, and in Georgia they rest on the more ancient crystallines (Pl., p. 557). The invasion is variable in time and character of deposits from place to place, beginning as a rule with fresh- to brackish-water sandstones that pass into clays and marls and locally into a thick deposit of impure chalks. The total thickness here is about 2400 feet. The "rotten limestone" or Selma chalk formation of Upper Cretaceous age in western Alabama and eastern Mississippi is 1000 feet thick, but east and west of this area the calcareous deposits are replaced by marls, clays, and finally sandstones. The thickness of these

eastern Cretaceous deposits does not exceed 1300 feet, and usually ranges nearer 500 feet.

Life of the Gulf Seas. — The younger Cretaceous faunas (Montana) of Texas are more harmonious with those of Mexico than with similar horizons of the Coloradic sea, being probably of waters with a higher temperature. Those of the eastern Gulf border take on more and more of the Atlantic border elements. Almost none of the warmer water rudistids and corals appear east of the Mississippi trough, though foraminifers, sea-urchins, and brachiopods occur here and northeastward, indicating the marine purity of the waters.

Vanishing of the Great Inland Seas

Final Continental Deposits. — We have seen that the marine Upper Cretaceous of the Rocky Mountains region also has intermingled with it a considerable amount of fresh-water formations, and that the latter tend to recur oftener toward the close of the period. Over them often lie other fresh-water deposits usually regarded as of Cenozoic age, and while in general geologists are agreed as to the line of separation between the Cretaceous and Eocene marine deposits, from the time work was begun in this region of the Great Plains investigators have been in doubt as to the division line. In recent years this question of classification has become acute, and though many of the best geologists and paleontologists have labored toward its solution, the problem is not yet satisfactorily adjusted. The field relations of the formations are fairly well known, but how much value shall be ascribed to the unconformable and disconformable contacts between the series of strata, and whether animals or plants shall be the deciding evidence, are still unsettled questions. As the sediments come from the same western source as those of the previous formations, they are consequently very much like the older ones. Again, the fossils are not markedly different in their evolutionary change between the accepted and the debatable Cretaceous formations. There is no lack of fossils in these beds and the difference of opinion among the stratigraphers lies in the fact that the students of invertebrate and vertebrate life find the Cretaceous faunas continued into beds which the paleobotanists hold have floras that are clearly Cenozoic in aspect. Or, briefly put, in the same strata the animals appear to be of Cretaceous kinds while the plants seem to be of the early Eocene.

Cannonball Formation or the Final Marine Cretaceous. — In various states of the Great Plains, evidences of late Cretaceous seas are found, the latest of which is that of the Cannonball member of the Lance formation of North Dakota, with a known extent of 130 miles. Lloyd divides the Lance into a lower member of continental deposits (400 feet), with dinosaurs, and a flora that

Knowlton says is indistinguishable from the plants of the Fort Union; and an overlying marine Cannonball member (300 feet), with a fauna of seventy-three species (Stanton 1920). Two are sharks, six are cup corals, two are foraminifers, and the rest are molluscs (thirty-one each of gastropods and bivalves, and one scaphopod). Of these forms but one type (brackish-water) passes upward into the Fort Union, while twenty-four occur below in the marine Fox Hills or older Cretaceous formations. Not one of the species is known in the marine Eocene province of the Gulf of Mexico, and of the latest Cretaceous faunas of the last-named province, not one passes into the Mesozoic. All of the Lance dinosaurs are therefore of Mesozoic age.

Paleocene. — In Europe and America, the formations that are debatably Mesozoic or Cenozoic in time have since 1874 been grouped under the term Paleocene, which means oldest Eocene. In the Great Plains of North America the Paleocene deposits are of wide distribution and include the Fort Union, Puerco, and Torrejon beds, with combined thicknesses ranging between 1000 and 2000 feet.

Fort Union, the Last of the Mesozoic. — The great changes in the animal assemblages of the Cenozoic strata, seen in the rapid vanishing of the old forms and the arrival of unheralded migrants from unknown regions, come later than those among the plants. Let us look into this subject to see what is its significance in Stratigraphy. The latest Cretaceous marine faunas vanish, and dependence for stratigraphic correlation is then held to be best among the land animals such as the dinosaurs and archaic mammals. The former in the Lance and the latter in the Lance and Fort Union are still Mesozoic in development, and besides, these formations pass one into the other unbroken, the very significant time break coming after the Fort Union. That the time is still Mesozoic during the Lance is seen in the return of the Coloradic sea, depositing the Cannonball marine strata replete with unmistakable Cretaceous invertebrates, closely allied with those of the earlier Fox Hills formation.

Since stratigraphers are agreed that the Pierre goes unbroken into the Fox Hills, and that the Lance does likewise into the Fort Union, we should digress a little here to point out that the Fox Hills also is continuous into the Lance, at least in most places in South Dakota. In other places, however, the Fox Hills was channeled to depths of 100 feet and to 600 feet in width. In such places there is an apparent angular unconformity between the Fox Hills and the Lance, since blocks of the former have slumped toward and into the hollows. Here, therefore, the Lance lies unconformably upon the Fox Hills, but elsewhere there is complete transition between these formations (F. Ward 1924).

After Lance time the climate is changing slowly to a drier condition, the dinosaurs are dying out for want of proper habitat, but the archaic mammals are rising into greater variety and size,

and so continue into the Eocene (Wasatch). After Fort Union time (including Puerco and Torrejon) comes the greatest elevation of the Laramide mountains, when the climate, at least locally, becomes alpine (tillites of early Eocene time are present in southwestern Colorado), and with the next higher formation, the Wasatch, come the heralders of modernity in the migrant placental mammals.

The evidence relating to the field relations and stratigraphy, the orogeny and paleogeography, and the invertebrate and vertebrate fossils of the Montana series and the Fox Hills and Lance formations is now well enough in hand to conclude that they all are unmistakably of Mesozoic time. Then, because the Lance and Fort Union are continuous formations; because these, with the Puerco and Torrejon, have wholly archaic mammal faunas and are followed by a period of greater orogeny; and since the succeeding Eocene deposits have wholly different and modernized mammal assemblages, the line separating the Mesozoic from the Cenozoic lies between the Fort Union and the Wasatch, and not between the Fox Hills and the Lance.

What we have been discussing here is the record of the "interval" between the Mesozoic and Cenozoic eras, a record that is usually absent at these "critical times." Some invertebrate and vertebrate paleontologists, therefore, prefer to hold that the time is still Cretaceous. Usually our classifications in Historical Geology recognize the beginning of a new period by the arrival of strangers, forms prophetic of coming dynasties, laying the stress upon these rather than upon the evidence of the "hold overs" from an older time. It is the placental mammals of the Wasatch that indicate Eocene time and the beginning of a new era, the Age of Mammals that is to culminate in man.

The student who wishes to work out this knotty problem for himself should consult the references cited at the end of this chapter.

Atlantic Shelf Sea

Upper Cretaceous formations are known all along the Atlantic border, either beneath or inland of the Cenozoic marine strata from South Carolina to the south coast of Massachusetts (see Pl., p. 557). They all dip seaward, though their original position is now warped due to elevation in the west. East of New Jersey the outcrops are scattering and mainly of brackish-water origin, while south of Maryland these deposits are seen only in the river valleys beneath the Cenozoic. Therefore the area yielding most informa-

tion is in New Jersey and Maryland. Here the deposits average between 1000 and 1325 feet, of which the lower 400 to 600 feet are either of fresh-water or brackish-water origin. Here, too, the materials are unconsolidated, and consist in the lower half of gravels, sands, and clays with lignite, while the upper portion is made up of clays and sands becoming more and more glauconitic and finally going over mainly into greensands. Glauconite is characteristic of the Atlantic overlap and at times is also found in considerable quantity in the eastern Gulf border.

Life of the Atlantic Cretaceous. — The marine invertebrate faunas are large, consisting of about 600 forms, in the main Mollusca (Pl., p. 575). Weller says that many of these have a wide distribution, as many of the New Jersey species also occur in the Gulf border area and mainly east of the Mississippi River. Further, the faunas indicate late Cretaceous time (Montana), and while definite but broad correlations can be made with the formations of the Coloradic sea, there are not many species in common between the two widely separated areas with which this can be done. This marked difference in faunas is thought to be due to colder waters along the North Atlantic shores. The floras occur mainly in the basal formations, where 150 forms have been discovered.

Invasion by the Pacific Ocean

Overlying the Lower Cretaceous (Shastan) strata of the Californic geosyncline disconformably, but usually unconformably, is the Chico series of sandstones and shales, with local conglomerates and coal beds. The coarse deposits and thick formations of the Chico are found in the British Columbic geosyncline all the way from the lower Yukon, the Alaskan peninsula (1000 feet), and the Queen Charlotte Islands (11,000 feet), to Vancouver Island (5000 feet); and in the Californic geosyncline from middle and southern Oregon (4000 feet), the Sacramento valley (9500 feet), and the Coast Range of California, to San Diego and the peninsula of Lower California, as far south as 31° 30′ (see Pl., p. 557). In California there were two periods of volcanic activity and in the Queen Charlotte Islands one of long endurance.

These beds begin somewhat earlier in time and continue longer than those of the Colorado series of the great Interior or Coloradic sea, but do not embrace, according to Stanton, the youngest Cretaceous time.

The Chico faunas were essentially molluscan, and, like those of the earlier Shastan (Horsetown), were of the Indo-Pacific province, and were markedly different from those of the Coloradic and Mexican seas. A few species of bivalves were common to the two areas mentioned, but these forms were world wide in their distribution. The evidence, then, is decidedly in favor of the view that the Pacific sea was shut out by a land barrier, the rising Rocky Mountains, from entering the Coloradic epeiric sea.

Part II. Crustal Movements, Climate, and Life

Laramide Mountains. — To the west of the Coloradic sea were the Central Cordilleran highlands discussed in the previous chapter. This arch or geanticline had been rising intermittently during the time of the Upper Cretaceous, while the Coloradic geosyncline or great inland sea was subsiding and receiving the vast detritals originating in the western highlands. When this arch was rising,

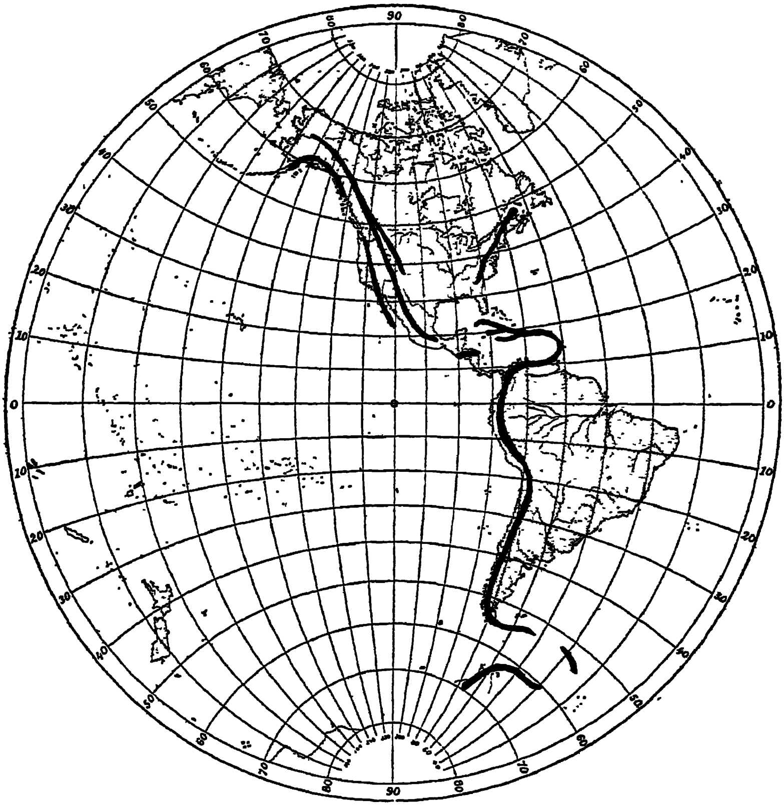

Fig. 195. — Stereographic map of the western hemisphere, after Penfield, showing the Laramide, Antillian, and Andean regions of folded mountains of late Cretaceous origin. The Appalachian area was reëlevated but not folded.

especially after Pierre time, the geanticline was studded with active volcanoes that extruded much lava. These lavas, eroding, furnished the andesitic débris seen so abundantly in the latest Cretaceous marine and continental formations. These eruptions continued with unabated vigor to the end of Fort Union time, and even into the early Eocene, and the volcanoes extended from Mexico City and Arizona north into Canada.

These volcanic eruptions were but symptoms of crustal movements, for mountain making of a folding nature, and thrusting toward the east on a vast scale (see Pt. I, p. 367), were going on during late Cretaceous time: the rising of the Rocky Mountains. The first period of marked orogenic movement, but the lesser of two, came at about Laramie time, and then during a long interval of orogenic inactivity the essentially fresh-water Lance and Fort Union formations were deposited to the east of the rising Laramide mountains. Finally, at the close of the Cretaceous (Fort Union time) and before Wasatch deposition, came the most intense folding, the actual *Laramide Revolution* of Dana. It was then that the Central Cordilleran highlands were transformed into the very long Rocky Mountains proper and the Colorado Ranges, culminating in many conspicuous peaks such as Pike's Peak, 14,100 feet, and Long's Peak, 14,221 feet, and continuing southward into the Sangre de Cristo Range of New Mexico.

The Laramide orogeny was equalled by that of the closing period of the Paleozoic, but was exceeded by the deformation of late Cenozoic time. The area affected embraced the Rocky Mountains from southern Mexico into arctic Alaska.

In Central Japan huge bathyliths of quartz-diorite and granite were intruded into the older rocks towards the close of the Mesozoic. Volcanic activity continued into Cenozoic time (Kato).

Along the Pacific coast in the areas of the Coast Ranges and the Klamath, Oregon, and Olympic mountains, the movements were small, and here the Cenozoic formations are as a rule not separated from those of the Mesozoic by an angular unconformity.

At the same time the Appalachians were reëlevated about 2000 feet (see Figs., pp. 567 and 569), due not to horizontal thrusting but to vertical uplift (see Pt. I, p. 396).

Birth of the Andes. — During the Paleozoic and Mesozoic there existed along the western side of the whole of South America a geosyncline, a subsiding area containing the Andeic inland sea. To the west of it stood a wide and repeatedly rising highland that was furnishing the rock materials for the Andeic sea. To the east of this sea lay a very extensive lowland, the Amazonian Shield, which in its history repeats the plains topography of the Canadian Shield.

In the middle of the Upper Cretaceous, and more especially in latest Mesozoic time, the Andeic geosyncline began to fold and rise into a mountain tract, the longest in the world. Beginning east of Trinidad off Venezuela, these mountains extend southwestward into Colombia and thence southward all along western South

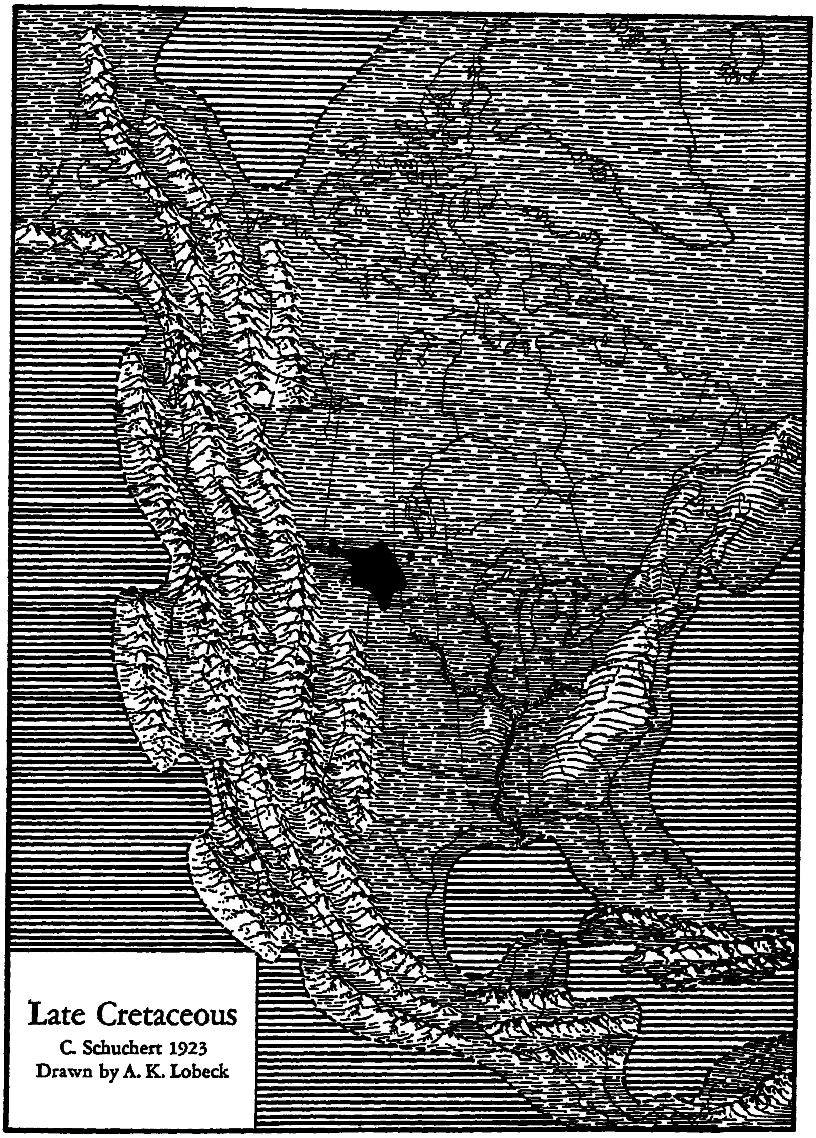

Plate 43. — Latest Cretaceous paleophysiography

Oceans ruled; lands in wavy lines.

Note that the continent is completely emergent, and that in the west it is newly risen into the Rocky, Cordilleran, and Pacific mountains, while in the east the Appalachian area is again domed (pp. 567–568). Antillis and Central America also are mountainous (p. 570).

The black spot is the area of Fort Union fresh-water deposits (pp. 563–565). The drainage of the Mississippi system is well established.

America to beyond Cape Horn, a distance of nearly 5000 miles. In the geology of South America they are what the Rocky Mountains are in that of North America. With the folding of the Andeic geosyncline, the highlands to the west of it began to founder into the depths of the Pacific Ocean. This borderland probably first broke up into island arcs similar to those now off eastern Asia, nearly all of which during the Pliocene and Pleistocene went down into the present great depths of the Pacific Ocean (see Fig., p. 567).

The Old Land Antillis. — Upper Cretaceous marine deposits are known in many parts of Cuba, consisting here of magnesian marls and glauconitic limestones. They occur also in San Domingo and Jamaica, where the Blue Mountain series, 5000 feet thick, begins with tuffs and lavas, passing into dark colored shales, marls, and limestones, all resting unconformably upon metamorphosed and igneous formations of older age. These deposits were greatly deformed and intruded by igneous material before the opening of Cenozoic time.

The fauna of the Mexican and Antillian seas was of the normal marine type, and of warmer waters. The molluscs abounded here, and the foraminifers, corals, and especially the cemented bivalves (rudistids, Fig., p. 574) flourished.

Geologists have long accepted as a fact the existence of an old land in the region of the greater Antilles, the Bahamas, and southern Florida. The origin of this land is, however, shrouded in deepest mystery and may go back into Proterozoic time, though the known fossiliferous strata begin with the Middle Jurassic of western Cuba. In many places, however, Mesozoic and Cenozoic formations are seen to rest upon a peneplained surface of greatly deformed and much metamorphosed rocks. This old complex is therefore held to be certainly as old as the Permian.

There is evidence of crustal deformation in the greater Antilles, and of the birth of mountains at the close of the Mesozoic, though their presence is much clearer at the end of Eocene time. Then mountains trending east and west extended from eastern Porto Rico and in going westward bifurcated, the southern range passing through the southwestern peninsula of Haiti into Jamaica and westward. The northern range passed westward through northern Haiti and southeastern Cuba into the Cayman Islands. Some geologists think these mountains continued unbroken even into Guatemala and Honduras.

"A series of fault zones extending along arcs that run approximately east and west have determined the major relief features in the region of the Greater

Antilles. Displacements along these fault zones have resulted in the formation of great trough-like valleys. The fault troughs are for the most part submerged beneath the Atlantic Ocean and Caribbean Sea and are, therefore, protected from erosion. They are characterized by great depth, precipitous inclosing scarps, abrupt changes in slope at the top and bottom, and relatively flat floors that, instead of being graded like river valleys, rise and fall throughout their length. The deepest places are close to the foot of the inclosing scarps rather than near the center of the trench, while horsts are also present along the fault zones" (S. Taber 1921). For further discussion of Antillis, see page 595.

Origin of the Greater Gulf of Mexico. — There was no lower Mississippi basin in the form seen to-day before Lower Cretaceous time because nearly all of the Gulf States since the Pennsylvanian had been more or less of a highland (but not a mountainous folded tract) that trended east and west. During all of this vast time, the drainage of the upper Mississippi River had flowed westward, either through the Arkansas valley or north of the Ozark dome, probably to empty into the Gulf of California. Toward the close of Lower Cretaceous time, in what is now the lower Mississippi valley, the land began to subside, and soon this sinking diverted the primal Mississippi River from its western course to its present southern termination. This downwarping is first seen in the state of Mississippi and finally the trough embraced all the area from central Alabama westward into central Texas. From the Gulf of Mexico the depression narrowed northward across these states and eastern Arkansas, western Tennessee and Kentucky into southern Illinois. The maximum extent of this basin was attained in the later Upper Cretaceous and early Cenozoic. Since then the general tendency has been uplift in the Gulf border states. During the time of the greater basin there were laid down in an intermittent sequence many formations that in the main are marine and may aggregate 10,000 feet in thickness.

In the northern portion of the Gulf basin the subsidence was mainly of the slightly downwarping kind, with the greater amount of sinking on the Arkansas side. On the flanks of the southern part of the trough, however, there was more or less faulting, and of a striking nature. In eastern Texas near the western margin of the Cenozoic formations there was a downthrow on the eastern and northeastern sides of from 1000 to 1500 feet. This took place in Cenozoic time and is evidenced in the Balcones fault that is clearly of early Cenozoic age (certainly post-Midway). Faulting of about the same time, and with greater throw, took place all along the eastern margin of Mexico, extending into southern Vera Cruz. Parenthetically it should be said that the inbreaking of the Gulf began in the south in Cretaceous time and continued at least to the close of the Eocene. On the eastern side of the Gulf basin, in northwestern Alabama, there was a downthrow of at least 10,000 feet (Hilgard 1871, and Branner 1897).

It should be added here that the Gulf of Mexico actually had its inception certainly as far back as Lower Cambrian time, when the Appalachic geosyncline, so far as can be seen from present evidence, continued across what is now Alabama and Mississippi, the deeper part of the Gulf, and southern Mexico (Tabasco, Chiapas, and Guatemala), into the Pacific Ocean. Throughout Paleozoic time this widened Gulf of Mexico portion of the Appalachic geosyncline appears to have been in existence, but beginning with the Upper Triassic the bounding southwestern land (Mexico) began to warp into the depths of the trough. In the Jurassic, and especially beginning with the Lower Cretaceous, not only parts of Mexico, but Antillis and the Gulf border states as well, began to be dragged into the depths, making during late Mesozoic and Cenozoic time the greater Gulf of Mexico. The present great depths of the Gulf of Mexico, and more especially of the Caribbean Sea, however, came into existence during the Cenozoic and seemingly after Miocene time.

Origin of the Indian Ocean, and the Greatest of Lava Flows. — During the Cretaceous and more especially in Upper Cretaceous time came the downbreaking of the lands bordering the Indian Ocean, and the development here of the present geography. At the same time, there began the transformation of the eastern end of the greater mediterranean (Tethys) from an area of deposition into one of land rising into the grandest mountains of the present, the Himalayas.

From south of Madagascar north to India, greater Africa, Arabia, and India were breaking down into a far larger Indian Ocean and the beginnings of the Arabian Sea. The first clear evidences of this foundering of the lands bordering the Indian Ocean are seen in the volcanic eruptions of Arabia in early Upper Cretaceous time (Cenomanian), and then later in this period the belching forth of greater and greater amounts of lavas became more general. These are the most colossal eruptions known to geologists. The outpourings began with the " plateau lavas " of Abyssinia and southern and northern Arabia (Senonian time) and later (Danian) were far more general in India and in the area of the present Arabian Sea.

Professor Wadia of Kashmir states that the lavas (commonly basalts, rarely rhyolite or trachyte) of peninsular India, emanating through fissures, cover an area to-day of at least 200,000 square miles, but that originally their extent was about two and a half times as great. In the north about Bombay they are nearly 10,000 feet thick, thinning rapidly to the east, and in the south of the peninsula their depth is between 2000 and 2500 feet. The individual flows average 15 feet but single ones are as thick as 50 feet. They are known as the *Deccan traps* and consist of basalts and trachytes. Since their origin they have been much jointed into a stair-like topography.

Eastern Africa during late Cretaceous time was being torn apart and greatly faulted, and long narrow blocks dropped several thousands of feet, forming the

rift valleys so characteristic of Africa and Arabia. The Red Sea and Lakes Nyassa and Tanganyika are examples. The maximum of rifting took place in middle Cenozoic time. Along with this fracturing of eastern Africa came marked volcanic activity, and the land was deeply covered with lavas. "The size of the area buried under volcanic material, the vast bulk of the ejecta, the variety of lavas, and the prolonged duration of the eruptions make East Africa one of the greatest volcanic regions of the world" (J. W. Gregory 1921. Also see E. Krenkel 1922).

Climate of Cretaceous Time

On an earlier page it was stated that the climate of late Jurassic times had marked climatic zones, and decided winters in the polar regions. This conclusion is further supported by the fact that in King Charles Islands (78° N.) Nathorst records in early Cretaceous strata the presence of fossil trees more than 3 feet thick, having over two hundred annular growth-rings. However, even before the middle of Lower Cretaceous time the floras, according to Berry, show that the earth was considerably warmer than it is to-day, with much less change from season to season, and therefore with a very long growing period. The rainfall was ample and fairly well distributed throughout the year. These conclusions are evidenced by the relatively indistinct rings of growth in the woods of this time, and by the presence of many cycadaceous and fern genera in Greenland, northern Alaska, western Canada, and Virginia, all clearly of tropical or subtropical kinds.

The marine faunas of the Lower Cretaceous were not of warm waters in the far north, for no coral reefs are known there, but their distribution was then in higher latitudes than it is now. In general we may say, therefore, that after early Upper Cretaceous time, when the marine floods were greatest, the climate the world over was milder than it is at present and that it was warm temperate in character (see Fig., p. 555).

Udden in 1918 described and illustrated what may be casts of ice crystals, indicating that winters with frost prevailed throughout the area of Texas and northern Mexico during the early part of the Upper Cretaceous (Eagle Ford) and the later part of the Lower Cretaceous (Del Rio). Shortly afterward, during the greater part of the Upper Cretaceous (later Benton to Fox Hills) the floras have palms, figs, and other warm-climate trees from Argentina to Greenland and Alaska. In Greenland (Atane beds) there grew breadfruit trees in addition to cinnamons, figs, laurels, tree-ferns, and other tropical and subtropical plants, indicating that the climate of this far northern land may well have been subtropical.

At the close of the Cretaceous in the "Laramie" of the Great

Plains there continued to live fig and breadfruit trees and palms, indicating a climate as mild as that of to-day along the Gulf of Mexico. In the later Fort Union, however, the climate in the Rocky Mountains was again cooler, with distinct though probably not severe winters, more like those in the present Dismal Swamp of Virginia and North Carolina.

It is very probable that climatic zones existed during the Upper Cretaceous, though not in so marked a degree as now. This is best seen in the distribution of the marine faunas, for in the Cretaceous formations of Tethys, Antillia, Mexico, and Texas, reef-building corals and bivalves (rudistids, Fig., below) are conspicuous, while in the deposits of North Europe and the American Atlantic border these animals are absent.

Fig. 196.—Reef-making, coral-like, rudistid bivalves (*Hippurites radiosus*), from the Upper Cretaceous of France. About half nat. size. In Jamaica these shells attained lengths of 7 feet.

We have seen that the Cretaceous closed with the Laramide Revolution, and in harmony with the earlier and later diastrophic movements of similar import, one expects to find here a cold, or at the least a considerably cooled climate. In confirmation of this expectation is the discovery by Atwood and Cross in 1923 of two beds of tillites in southwestern Colorado, which have been traced over an area of 40 miles in length, and represent the work of Alpine glaciers. Their age is not certainly known, though Cross holds that they are probably of early Eocene time, just when the Laramide Mountains were most extensive and highest.

There is now good evidence of glacially striated stones of wide

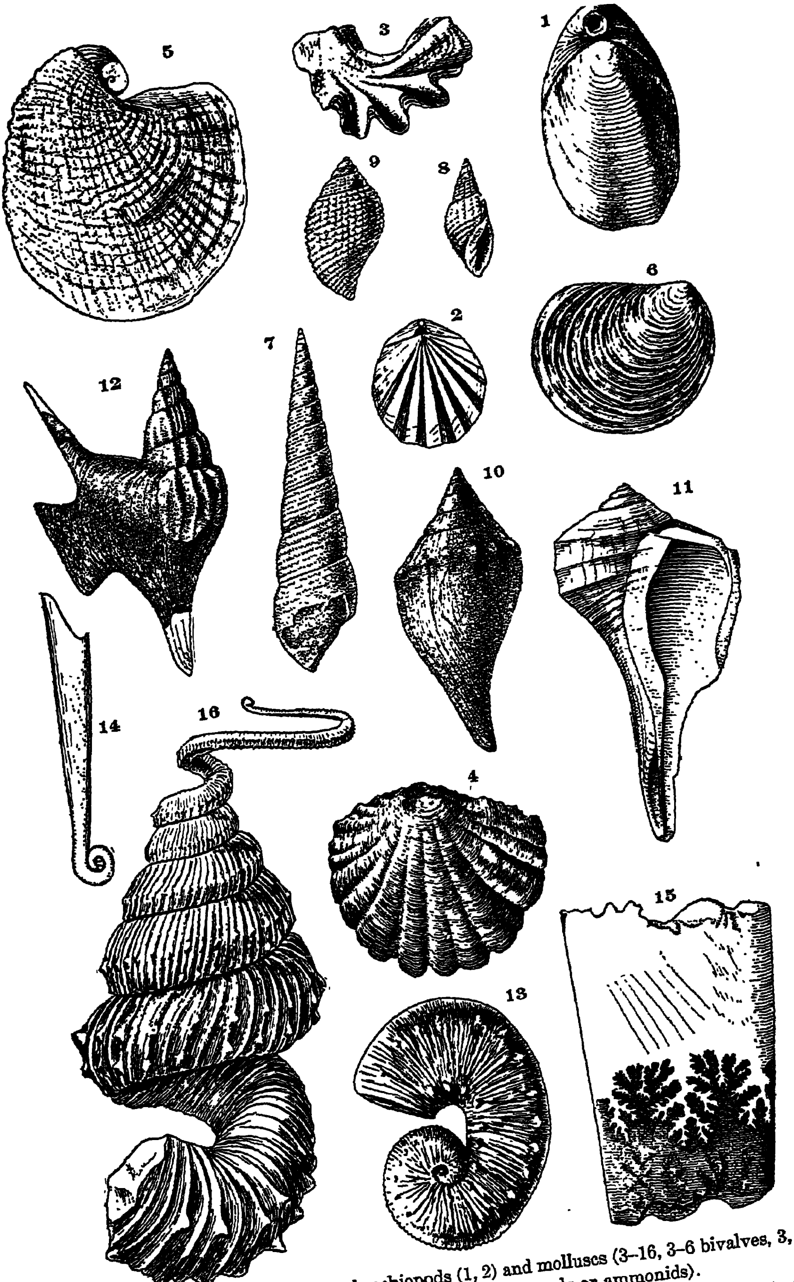

Plate 44. — Upper Cretaceous brachiopods (1, 2) and molluscs (3–16, 3–6 bivalves, 3, 4 oysters, 7–12 gastropods, 13–16 cephalopods or ammonids).

Fig. 1, *Terebratula harlani*, × ⅔; 2, *Terebratella plicata*; 3, *Ostrea larva*; 4, *O. lugubris*; 5, *Exogyra costata*, × ½; 6, *Inoceramus vanuxemi*, × ½; 7, *Turritella whitei*; 8, *Admetopsis subfusiformis*; 9, *Cancellaria malachitensis*; 10, *Cryptorhytis utahensis*; 11, *Pyropsis bairdi*, × ½; 12, *Aporrhais prolabiata*; 13, *Scaphites nodosus*, × ½; 14, *Baculites compressus*, × 10; 15, fragment of an adult of same species, to show suture [illegible]. After Stanton, Whitfield, and Scott.

distribution in late Cretaceous deposits of central-southern Australia. The discovery was first made by Talbot and Clarke, and then confirmed by Brown (Benson 1923).

Life of the Upper Cretaceous

The most striking aspect of the life of the Cretaceous was the culmination of the dinosaurs, pterosaurs, and reptilian mammals that began in the Triassic, the toothed birds of Jurassic origin, and the marine faunas of Jurassic time. It was the final expression in the

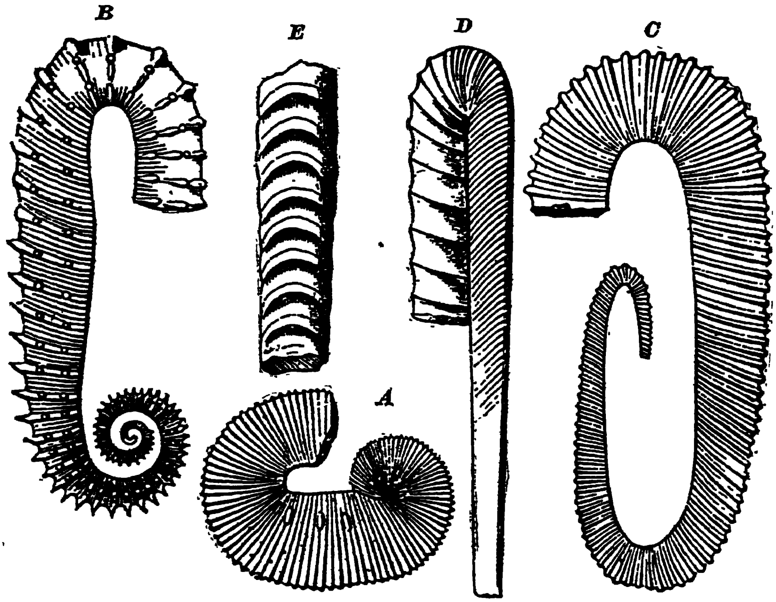

Fig. 197. — Bottom-feeding forms of ammonids, the descendants of swimming ancestors. Lower and Upper Cretaceous of Europe. From Heer's *Primeval World*. *A*, *Scaphites hugardianus*; *B*, *Ancyloceras matheronianum* (Aptian), × ⅓; *C*, *Hamites rotundus* (Gault); *D*, *Ptychoceras puzosianum* (Neocomian); *E*, part of straight cone of *Baculites gaudini*.

evolution of the medieval life, and out of it arose the modern world of organisms.

Invertebrates. — The *marine* invertebrate animals were much like those of the earlier Cretaceous (see Pl., p. 575), with the marked difference that the ammonids were making their last stand. Old age was upon them, since but few new genera arose, and their doom was foreshadowed in the uncoiling, the unnatural twisting of the shells (Pl., p. 575, Fig. 13), and the straight baculites (Fig. *E*, above, and Pl., p. 575, Figs. 14, 15). The genus *Heteroceras* displays the extreme of

irregular growth (Pl., p. 575, Fig. 16). The belemnids were still present in force, though by no means so abundant as in the Jurassic, and they were evolving toward the squids in the loss of their internal vestigial structures.

In the *fresh waters*, unionids or pearl shells were common, and very much like those now living in the western streams of the United States. Fresh-water snails and *land snails* (*Helix*, Fig. *C*, p. 224) are also found, though less commonly.

Floras. — There was nothing medieval in the character of the later Cretaceous flora, for more than 90 per cent of the plant genera were of the woody kinds known to-day. The magnolia, fig, and sassafras trees, of Lower Cretaceous origin, were in their best development in the later Cretaceous. Other modern trees that appeared in this period were the birch, beech, maple, oak, walnut, hazelnut, plane, tulip, laurel, holly, ivy, sweet gum, and breadfruit. The giant trees of California, the sequoias, of early Mesozoic origin, were also in their ascendancy. The sedges and grasses appeared in Upper Cretaceous time, but it was not until late in the Eocene that the latter and the cereals became abundant, and thus made possible the rise of the higher or placental mammals.

Little is as yet known of the *insects* of the Upper Cretaceous. It appears probable, however, that most of the modern orders were then present, and also that much adaptation in the visiting of flowers to eat the pollen had already taken place, and that through this environment had come other changes modifying the mouth parts into tubes to suck the flowers of their honey. Through these visitations arose the dependence of plants upon their guests for pollenation.

Dinosaurs. — During Upper Cretaceous times the dinosaurs were very varied and the individuals large in size. The most characteristic were the Ceratopsia, horned animals some of which were twice as heavy as elephants (Pl., p. 485, Figs. 1–5). The duck-billed forms were large and represented by distinctively American kinds not only in the Rocky Mountains but also in New Jersey (*Trachodon* or *Claosaurus*, Pl., p. 485, Fig. 6). Large sauropods were, however, rare. Upon these various forms preyed the carnivorous kinds, among which was the king-tyrant saurian (*Tyrannosaurus rex*, Pl., p. 485, Fig. 7), the most fearful of all flesh-feeding animals.

Until recently it was thought that the ponderous quadrupedal sauropod dinosaurs became extinct with the Upper Jurassic (Morrison) or at latest with the early Lower Cretaceous (Arundel). In 1922, however, Gilmore described the partial remains of a fairly large sauropod shoulder blade from the later Cretaceous (Ojo Alamo) of New Mexico. With this discovery, it is now all the more easy to believe that the dinosaurs of Argentina are also of late Cretaceous time and that among them were sauropod forms.

Near the close of the Cretaceous (Lance) the life of the land was still dominated by the dinosaurs, and nearly all were large forms. They were living in a forest of Cenozoic aspect, since the progression among the plants was ahead of that of the animals. Even though the Rocky Mountains were rising and the Great Inland Sea along whose shores in the fresh-water swamps they lived was vanishing, the dinosaurs continued on without apparent check. With the going of the last Cretaceous sea (Cannonball) these great beasts so characteristic of the medieval world died out, there being none in the Fort Union.

Fig. 198. — A scaled Upper Cretaceous mosasaur (*Clidastes*). from Kansas. Restoration by Williston, from University of Chicago Press.

Reptiles of the Sea. — The seas of Upper Cretaceous time continued to be dominated by reptiles. The ichthyosaurs were vanishing, but the plesiosaurs attained their culmination, for a form has been found in Kansas which had a length of 40 to 50 feet, of which 22 feet was neck (*Elasmosaurus*, Fig., p. 559). The crocodiles were represented by the ancient broad-nosed, long-headed type (*Teleosaurus*), and by the first of the slender-nosed kinds, such as the gavials living to-day in the rivers of India and Borneo. Of marine turtles, at least one kind was present; the largest specimen known was nearly 11 feet long, with a breadth across the front flippers of 12 feet (*Archelon*). But the most interesting of the newly appearing animals were the scaled reptiles known as mosasaurs, which were confined to the Upper Cretaceous. They swarmed in the shallow seas along the Atlantic border and the Gulf of Mexico, and especially in the seas of Kansas. The mosasaurs were gigantic, carnivorous, marine lizards, ranging in length up to 35 feet, with the limbs modified into swimming paddles (see Fig., above).

Toothed Birds. — The last of the toothed birds are seen in the Upper Cretaceous of Kansas. They are discussed in Chapter XL.

Mammalia. — Many jaws of diverse kinds of mammals have been found in late Cretaceous deposits (early Lance) of Wyoming and Montana, but they did not as yet play an important rôle among the land animals of their time; nearly all were still small and of archaic character. Later, in Fort Union time, and immediately after the dinosaurs had vanished, they began to attain larger size and tended to become the dominant animals of the lands. At

Fig. 199. — Swimming reptilian bird (*Hesperornis regalis*) from the Upper Cretaceous of Kansas. Restoration by Gerhard Heilmann. See also Fig., p. 559.

least forty kinds are known, and six or seven orders. The most remarkable of these are the five genera of primates in the Fort Union formation (Gidley 1922). Since they are already varied here, it is evident that the origin of the pre-human line in the lemurs goes far back into the Cretaceous.

Great Mortality of Cretaceous Time. — We have learned that early in the Upper Cretaceous the oceans began to spread over the

continents, and that this transgression was one of the greatest of the geologic past (see Fig., p. 555). It therefore is interesting to note that even though there was great opportunity for expansive evolution, but few new marine stocks appeared. On the contrary, it was rather a time of death to many characteristic ones. Entire races of specialized forms vanished, just as other stocks did under similar circumstances (= critical period) at the close of the Paleozoic. In late Cretaceous times it was the ammonids, belemnids, rudistids, and other stocks of molluscs which disappeared. In addition, there was a great reduction among the reef corals, the replacing of the dominant ganoids by the teleosts or bony fishes, and, finally, the complete dying out of the various stocks of marine saurians.

On the land, with the establishing of the highest or flowering plants, we see the vanishing of the dragons or pterodactyls, and, near the close of the Cretaceous, the last of the dinosaurs and the birds with teeth; they were overwhelmed by climatic changes and the rise of the mammals; in the air they yielded to the more finely organized birds — in short, the reptilian dominance was destroyed with the end of the Mesozoic era, during which entire time they had been the characteristic animals of the sea and even more of the land.

The great reptilian bubble swelled up and burst at the close of the Cretaceous, leaving behind a few crocodiles and lizards for to-day. Out of the crash of the reptilian overgrowth and extravagances the birds emerged with a promise still ahead, while the mammal line leading into man traveled clear of the hindering excesses (Clarke).

Economic Products

Coal. — Just as the Pennsylvanian, at the close of the Paleozoic in eastern North America, was the period of greatest coal making, so was the Upper Cretaceous in the Rocky Mountains country at the close of the Mesozoic (see Fig., p. 402). Some coal was laid down in all of the formations of the Upper Cretaceous, but most of it in the closing time of the period. It is coal formed *in situ*, in local swamps ranging from Arizona into Canada, and occurs in both thin and thick beds (even up to 86 feet), and, as in the Pennsylvanian, usually in many superposed beds. These coals are composed in the main of conifer woods, of sequoia or "big trees," cypress, juniper, fir, and spruce. Throughout the Rocky Mountains of the United States there are more than 100,000 square miles of coal-bearing lands, and Colorado alone is estimated to have 34,000,000,000 tons of available coal, most of which is of Upper Cretaceous age. These coals range in grade from lignite to anthracite.

Petroleum. — Much natural oil is being mined out of the Upper Cretaceous strata of Montana, Wyoming, and Texas, but in greatest amount in the Gulf coastal plain of Mexico. Here there are two main producing areas, (1) the Tampico-Tuxpan, and (2) the Tehuantepec-Tabasco. The wells are down between 2000 and 3000 feet. Single wells have yielded 260,000 barrels per day, and one has given 40,000,000 barrels in five years. Mexico has been the third largest oil-producing country, but at present the yield is greatly reduced due to salt water entering the wells.

Gold and Silver. — Lindgren says that from Cape Horn to Alaska the gold and silver deposits of the Cordilleras were formed under similar geologic conditions, at different times between the earliest Cretaceous and the present. They are the products of the igneous activity that accompanied the rise of these gigantic mountains. The hot waters ascending from the molten rocks carry in solution gold and silver, and on becoming cold, deposit the metals in what are known as primary or original deposits. The placer gold is derived from the primary veins through their disintegration under weathering influences.

In North America the annual yield of gold now has a value of about $130,000,000 and silver of about $100,000,000. This yield is ten times greater than the present production of South America. Mexico is the greatest producer of silver and during the past four centuries has yielded 122,500 metric tons. Colombia, Chile, Bolivia, and Peru have also produced greatly in the past.

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CHAPTER XL

THE TOOTHED BIRDS OF MEDIEVAL TIMES

In all of the present lands and on the surface of the seas there are living more than 15,000 kinds of birds, not one of which has teeth. Even in the unhatched embryo, teeth are discernible in but few forms, and then only as the merest rudiments. In the Cenozoic about 650 species of birds grouped in nearly 400 genera have been described, and here as in the living world all so far as known are toothless. Fossil birds are, however, exceedingly scarce until the Miocene and later deposits. Skulls of birds are very rare back of the Pleistocene, but in the early American Eocene (Green River) there is known a fine skeleton the skull of which is also devoid of teeth. All of which serves to emphasize the chief character distinguishing medieval birds, which is the *possession of teeth.*

Fossil eggs are known in eleven different kinds, one of Cretaceous time, the others of late Cenozoic. Feathers are preserved in nine species, and probably the finest impressions of such occur in the Solenhofen deposits of Upper Jurassic age. In the Mesozoic, good skeletons are known of about a half dozen species, all reptilian in character and provided with teeth.

Origin of Birds. — It is now widely accepted that birds in their general construction, and especially in their brain, skeleton, reproductive organs, and mode of development, are "glorified reptiles." The older idea of Huxley that the birds arose in the dinosaurs has given way to the theory that in late Permian or early Triassic times a small ground-living lizard-like reptile of partly bipedal habit adapted itself to living in bushes and trees, probably for purposes of safety. The arboreal habitat, it is thought, led these reptiles to learn how to fly. These remote and primitive ancestral reptiles (Diapsida) are believed to have lived probably in the Pennsylvanian, and later to have given rise not only to the birds, but as well to the dinosaurs, pterodactyls, and yet other reptilian groups. The progenitors had small brains, comparatively sluggish habits, and a highly variable body temperature. During the trying arid climates of the Permian and Triassic were evolved hardier and more active warm-blooded carnivorous reptiles. Some of them when running

probably reared up on their hind legs, as do certain living lizards. These more active running and bipedal pro-avian lizards probably had their entire body covered with overlapping scales, and jumping about from branch to branch or tree to tree, learned not only to parachute, but eventually to flap their front limbs in aviation. In these efforts the scales changed into long and complicated fronds and finally became feathers that maintained the body warmth, the front limbs developed into wings, the skeleton became lighter (hollow and pneumatic), and in addition the body filled with an extensive system of air cells to help buoy up the bird while in flight. Birds are at once further distinguished by having feathers, a dermal feature which is as characteristic of them as hair is of mammals.

Jurassic Birds. — Birds appear as fossils for the first time in the Upper Jurassic and represent one of the most remarkable advances which the life of this period has to show. As yet, only a single kind of Jurassic bird has been found, and this is from the highest division, near Solenhofen, Germany. This bird, about the size of a large pigeon, is called *Archæopteryx* (Greek for *ancient wing*). It is also known as the lizard-tailed bird. It has many points of resemblance to the reptiles, and many characters which recur only in the embryos of modern birds (see Figs., pp. 583 and 584).

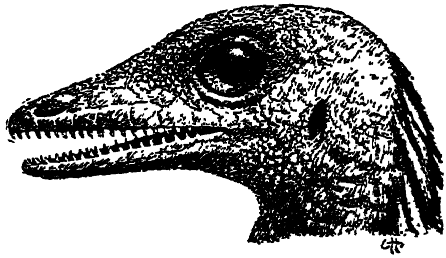

Fig. 200. — Head of *Archæopteryx*, as restored by Heilmann.

The peculiarities which strike one at the first glance are in the head and tail; there was no horny beak, but the jaws were set with a row of small teeth, while the tail was very long and in shape like the leaf of a date palm, composed of separate vertebræ (about 20), and with a pair of quill-feathers attached to each joint. This construction shows at once that in *Archæopteryx* the tail was not at all like that in modern birds, i.e., fan-like, with the vertebræ all anchylosed and the large feathers folding upon one another. The wing was constructed on the same plan as that of a modern bird, but was decidedly more primitive. The four fingers were all free (in recent birds two of the three fingers are fused together); they had the same number of joints as in the lizards and were all provided with claws. The plumage was thoroughly bird-like in character, but was peculiar in the presence of quill-feathers on the legs, and apparently also in the absence of contour feathers from the head, neck, and much of the body, leaving those parts naked. This very extraordinary creature was, then, a true bird, but had retained many features of its reptilian ancestry.

In northeastern South America there lives one of the remarkable links with the past, the bird known as the hoatzin (*Opisthocomus*). It is the only known living bird having five fingers on its wings. The adult bird is said by Beebe to be reptilian in voice, action, fingers, and habits. The voice, a hoarse and croaking one, is frog-like. As babies "they crept on all fours, they climbed with fingers and toes, they dived headlong and swam as skillfully as *Hesperornis* of old."

Fig. 201. — Restoration of the most ancient known bird (*Archæopteryx macrura*), illustrated as feeding on the fruit of a cycad; in reality, however, these birds were carnivorous. After Gerhard Heilmann.

Cretaceous Birds. — In the early Upper Cretaceous strata of Kansas are found from time to time most excellent skeletons of large reptilian water birds of a species which Marsh called the "regal western bird" (*Hesperornis regalis*, Figs., pp. 559 and 579). It was in this genus that teeth in birds were first noted by Marsh and this discovery led him to predict that when the head of *Archæopteryx* was found it would be seen also to have teeth. The skeleton of *Hesperornis* measures 6 feet in length, though it did not stand higher than 4½ feet; its wings were vestigial and of no use in air or water, but the great feet were webbed, and paddled in the sea, curious as it may seem, with outward lateral instead of downward strokes. The greater part of their lives was spent in the sea, and on the land they were more helpless than loons, humping themselves along as do the seals. Associated with these are found very rarely other much smaller birds with powerful wings (*Ichthyornis*, Fig., p. 559), which looked much like modern gulls and terns. Both of these birds, like those of the Jurassic, had small curved teeth and were flesh feeders.

There is a great deal of difference between the truly reptilian birds of the Upper Jurassic and those known next in the later Cretaceous. Lucas says these differences are greater than between those of the Cretaceous and the present. The older ones had long reptilian tails with the feathers in pairs on either side, while those of the Cretaceous appear to have had fan-shaped tails as in living birds. The distinctly three-fingered wings of *Archæopteryx* are united in Cretaceous birds for the support of the feathers, but the skulls of all Mesozoic forms are still reptilian in that the bones are not completely united as in living forms.

Origin of Flight. — A heavy and cumbersome flight was clearly present in Upper Jurassic time (*Archæopteryx*) and excellent flight in small birds such as *Ichthyornis* in the Upper Cretaceous. In the late Cretaceous, the toothed birds of large size (*Hesperornis*), although devoid of flight, were great divers in the Kansas seas in search of fish. Toward the close of the Mesozoic it is thought that all birds began to lose their teeth and those with flight well developed deployed into the modern toothless types, while those with poor flight (but not *Hesperornis*) gave rise to the flightless and toothless running birds like the ostriches and the even greater moas of the southern hemisphere.

Two theories have been advanced explaining the origin of flight in the stages succeeding the arboreal phase of bird evolution, the pair-wing or *Archæopteryx theory*, and the four-wing or *Tetrapteryx*

theory. These theories are illustrated in the figure below. Both of these hypotheses assign two phases to the origin of flight in birds;

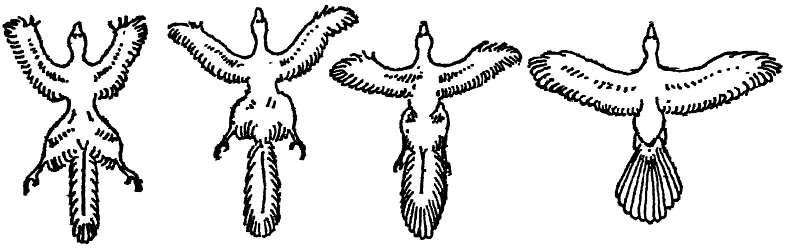

Fig. 202. — Four figures illustrating the origin of flight in birds. The first illustration on the left is of the hypothetic four-winged (tetrapteryx) flight, evolving into that of *Archæopteryx* (second figure), and in the last two figures into the mode of flight in modern birds. After Beebe, redrawn from Lucas' *Animals of the Past*.

first, a primary ground-living phase during which the peculiar characters of the hind limbs and feet were developed, with their strong analogies to the bipedal feet of dinosaurs; second, a purely arboreal phase leading to well developed flight.

Fig. 203. — Restoration of a giant bird of Miocene time found in Patagonia (*Phororhacos*). The skull is as large as that of the largest horse. From Lucas' *Animals of the Past*.

Loss of Flight. — It is believed by the adherents of both these theories that following the tree-living or flying phase of birds, there occurred among the larger and therefore heavier ground-living forms (usually spoken of as struthious, the term having reference to ostriches), a secondary ground phase in which the power of flight was lost and a running locomotion re-developed. From the flying birds descended the water-living types, in some of which the wings are also lost, as in *Hesperornis*, which has only a vestige of the wings left, or in the living penguins in which the wing is changed into a swimming paddle. The divers of the Cretaceous seas represent one of the many instances where land-adapted forms become wholly aquatic, and their transformation developed as a result of the new habitat, resorted

to because of its greater amount of more easily obtainable food.

Nearly all the continents at some time during the Cenozoic had large ground-living ostrich-like birds. The tallest and heaviest of these were the moas of New Zealand, exterminated by the Maoris five or six centuries ago. There were about twenty kinds, the largest of which, *Dinornis maximus,* stood 10 feet high, 2 feet above the largest ostrich. Another closely related but smaller form was *Æpyornis* of Madagascar, a bird that laid the largest of all known eggs, 9 by 13 inches. It was the finding of these eggs by the early navigators that led to the vast exaggerations which thrill the reader with wonder and terror in the accounts of the Roc given by Sinbad the sailor in the Arabian Nights.

During early Eocene time there lived in Wyoming a gigantic running bird with only vestiges of wings, known as *Diatryma.* A specimen of this mounted in the American Museum of Natural History stands nearly 7 feet high, and shows a short but massive neck surmounted by a head as large in size as that of a horse. The most powerful of all ground-living birds of Cenozoic time, however, was *Phororhacos,* found in the Pampas formation of Argentina, standing 7 to 8 feet high, with a skull 23 inches long, heavy, and decidedly beaked, apparently the most terrible of birds of prey. It was not at all related to the ostriches, but rather to the living herons (see Fig., p. 586).

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CHAPTER XLI

THE DAWN OF THE RECENT IN CENOZOIC TIME

Long ago Newberry said that the picture which Geology holds up to our view of North America during the greater part of Cenozoic time is, in all respects but one, more attractive and interesting than could be drawn from its present appearance. Then a warm and genial climate prevailed from the Gulf to the Arctic Ocean, and most of the continent exhibited an undulating surface of rounded hills and broad valleys covered with forests, inhabited by birds and animals far more varied than any of the present day, or wide expanses of rich savannah over which roamed countless herds of mammals, many of gigantic size, of which our present meager fauna retains but a few representatives.

Fig. 204. — Sir Charles Lyell (1797–1875). Author of *Principles of Geology*.

The Various Time Terms. — About Paris, France, the marine formations of the Anglo-Gallic basin are interbedded with continental deposits and therefore these two usually independent records, one of the oceans and the other of the lands, are checks upon each other. The shells of the marine formations were studied by Lamarck (1818–1822) and Deshayes (1824–1837), the mammals by Cuvier (1812), and the plants by Brongniart (1822–1828). The numerical relations of the Cenozoic faunas to those of the present were first indicated by Cuvier, and followed out in detail by Deshayes and Lyell. Deshayes recognized nearly five thousand kinds of shells and the study of these led him to see that the youngest strata had the greatest number of still living species, while the forms found in the oldest rocks had the least faunal resemblance to those of the

present. He also pointed out that in the Cretaceous there are no species of the present living world, and it was this observation that led to the establishing of the Cenozoic as the era in which the present life dawned. This change or evolution among the shells was taken by Charles Lyell (Fig., p. 588) in 1832 as the basis for dividing the Cenozoic formations into *Pliocene* (from the Greek words meaning *more recent*, 35 to 50 per cent of the species still living), *Miocene* (*less recent*, 17 per cent still living), and *Eocene* (*dawn of the recent*, 3.5 per cent still living). To these Lyell later added *Pleistocene* (*most recent*, 90 to 95 per cent still living); and in 1854 Beyrich separated out the older Miocene formations under the term *Oligocene* (*little of the recent*).

A wider knowledge of the marine Cenozoic molluscs has shown that this classification has permanent value, but that the percentage of living species is about as follows (see also p. 590):

Cenozoic era	Younger or Neogene group	Pleistocene epoch,	90–100	per cent of living Mollusca
		Pliocene epoch,	50–90	" " " " "
		Miocene epoch,	20–40	" " " " "
	Older or Paleogene group	Oligocene epoch,	10–15	" " " " "
		Eocene epoch,	1–5	" " " " "

The percentage of living shells in any Cenozoic formation is variable, as the above table shows, and the newer work in Japan and the Philippines, where the waters have remained continuously warm, appears to indicate that in the warm temperate and equatorial belts of the earth they may not hold at all. (Dickerson.)

During the rise of the science of Geology, the youngest era in the history of the earth was named *Tertiary* by Cuvier and Brongniart (see p. 453), it being thought that all earlier time was comprised in but two other eras. Later came into use the term *Quaternary*, which included the youngest geologic formations of more or less unconsolidated materials scattered over the surface of the earth. Since, however, Quaternary is not representative of an era of geologic time, and since six areas are now recognized by geologists, we had best abandon both these terms and use only one, *Cenozoic* (from Greek words meaning *recent* and *life*). Recent time will then start when the Pleistocene continental glaciers began their final melting off northern Europe and North America, seemingly not more than 20,000 years ago.

It has long been the custom to divide the Cenozoic into two parts, an Old or *Paleogene* and a New or *Neogene*. This is done for the fol-

lowing reasons. The Paleogene (Eocene and Oligocene) begins with inherited highlands that later are gradually reduced to peneplains. The climate is at first cool, but with the vanishing of the mountains it becomes warmer, moister, and equable. The Oligocene is the most widely spread warm time of the Cenozoic, and the animal life of the land and seas is still ancient. In the Neogene (Miocene, Pliocene) there is much crustal unrest, seen in the rising of mountains, in consequence of which there appear cooler climates that attain their climax in the late Pliocene and the following Pleistocene. The life is decidedly modern.

TABLE OF CENOZOIC FORMATIONS (MAINLY AFTER VAUGHAN,

	Epochs	Atlantic Border Marine	Florida-Alabama Marine	Pacific Border Marine	Western Interior Fresh-water Formations	Europe Marine
	Pleistocene		Pleistocene	Pleistocene		Pleistocene
	Pliocene	Break Waccamaw Break	Caloosahatchie = Citronelle	Break Merced Break	Break Blanco Break	Sicilian Astian Plaisancian
Neogene	Miocene	Chesapeake Break	Jacksonville = Pascagoula Break Alum Bluff { Shoal River, Oak Grove, Chipola }	San Pablo Monterey { Salinas, Vaqueros }	Arikaree { Break Deep River Break }	Pontian- Sarmatian Tortonian Helvetian Burdigalian
	Oligocene	Break	Tampa = Chattahoochee Vicksburg Antigua Marianna	San Lorenzo Break	John Day White River { Brule, Chadron }	Aquitanian Chattian Rupelian Lattorfian
Paleogene	Eocene	Cooper = Barnwell Break McBean, Congaree } = Pamunkey Williamsburg Black Mingo	Ocala = Jackson Claiborne { Gosport, Lisbon, Tallahatta } Wilcox Midway	Tejon Meganos Martinez	Uinta Bridger Green River Wasatch	Ludian- Bartonian Anversian- Lutetian Ypresian Sparnacian

The question is often asked, of what significance in chronology are such terms as Eocene, Oligocene, Miocene, and Pliocene? Some regard them as of the value of periods, but clearly none represent the length of time or show the amount

of organic evolution that the periods do in the Mesozoic or Paleozoic. It is now held that the Cenozoic represents from 4 to 5 per cent of all geologic time, while the Mesozoic endured 11 to 12 per cent and the Paleozoic 28 to 30 per cent. In other words, the whole of the Cenozoic endured no longer than the average time of a Paleozoic period, and while the evolution of the mammals is very marked, that of the other organisms is no greater than in a period of time. Accordingly the subdivisions Eocene, Oligocene, Miocene, Pliocene. and Pleistocene are here treated as epochs of time or series of strata.

PART I. THE NORTH AMERICAN CENOZOIC

Areas of Marine Sedimentation

The seas of Cenozoic time in North America, excepting in California, were typically marginal overlaps of the oceans, and were of the nature of shelf seas. There were almost no inland or epeiric seas, in contrast to their dominancy during the Paleozoic and less markedly during the Mesozoic. The marine overlaps oscillated back and forth repeatedly and variably in the different areas of invasion, but at no time was more than 6 per cent (Middle Eocene) of the present area of North America under water, while the average for the Cenozoic was about 3 per cent or even less. If, however, we include Central America and the Antilles, the total percentage may rise to 10 per cent, with the time of most marked flooding during the Oligocene epoch (Pl., p. 593).

In Europe and Asia, the marine overlaps were also less extensive than during the earlier eras, but Tethys continued in full extent from western Europe to India, and attained its greatest spread in Oligocene time. Its connections with the Atlantic were limited, and for a time it had Arctic connections east of the Urals. The Alps of southern Europe and the Himalayas of India began to rise in the Miocene and then the eastern half of this extensive middle ocean began to vanish more and more. In the Pliocene, Tethys had attained about the area and the general configuration of the present Mediterranean; but in these alterations the remaining areas of former shallow seas had been changed to a chain of great basins of oceanic depths — an epeiric sea had given way to a mediterranean ocean.

The capital cities of many European countries are built on Cenozoic strata, among them London, Paris, Brussels, Rome, Vienna, and Berlin.

In southern Europe, northern Africa, Asia Minor, India, Burma, Siam, Sumatra, and Java, the stratigraphic and tectonic history is that of Tethys; in eastern Asia, Melanesia and Australasia, the very intricate record is that of the Pacific. These two types of

mountains meet in the Dutch East Indies to the north of Australia. In North America there were marginal pulsations of the Atlantic, the Gulf of Mexico, and the Caribbean, but along the Pacific the history is more in harmony with that of eastern Asia.

Degree of Consolidation of Strata. — Where the Cenozoic strata have not been deformed, they are apt to be unconsolidated and soft, as in the marine formations along the Atlantic border and in the continental deposits of the Rocky Mountains. Along the Pacific coast, however, nearly all of the formations older than the Pleistocene are folded or otherwise altered so that they are as much consolidated as are the formations of the Paleozoic.

Overlaps of the Atlantic Ocean. — Wherever the contact between the Cretaceous and the Eocene has been seen from New Jersey to central Mexico, the Eocene sea advanced across a land surface which had reached an old or nearly base-leveled stage of erosion, as is shown by the almost horizontal contacts (see Fig., p. 561). Not a single species of the Mesozoic is known to pass this break into the Eocene. Much of the time of this break is represented in the Rocky Mountains by continental deposits, the Lance, Fort Union, Puerco, and Torrejon, which in this book are referred to the Mesozoic.

The Cenozoic deposits of the *Atlantic Coastal Plain* north of North Carolina (Cape Hatteras) are not at all as well developed as those in the states bordering the Gulf of Mexico, and no Eocene strata are present north of New Jersey. A limited Lower Eocene development of marine greensands and marls not over 225 feet thick occurs in Maryland, Delaware, and Virginia. Upon these follow, after a long interval of land conditions, the Chesapeake Miocene sands, clays, marls, and diatomaceous earth, with a thickness ranging up to 475 feet (see Pl., p. 593). Marine Pliocene strata are of very limited and occasional development.

All of the Cenozoic strata dip toward the Atlantic Ocean, or the Gulf of Mexico.

Along the eastern Gulf Coastal Plain from Cape Hatteras southward and westward, the marine Cenozoic is well represented, with the longest sequence of the older strata in Alabama and Mississippi and of the younger ones in Florida. In the north, toward the old shore, it is a variable series of sands, greensands (glauconite), and marls, with more or less of lignite beds, while in Florida occurs an unequaled development of Oligocene and Miocene limestones and marls, with but little sand. The thicknesses are variable, often under a few hundred feet, and at best attain to over 2000 feet. In Florida the

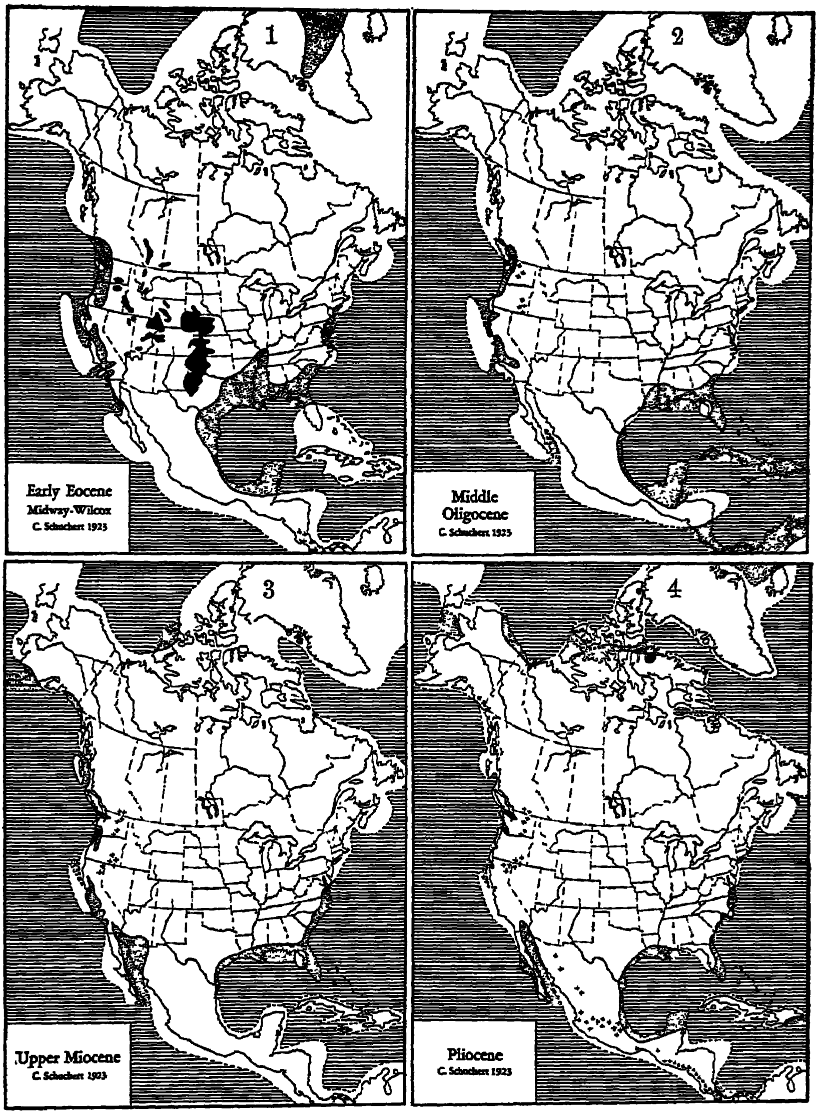

Plate 45. — Paleogeography of Cenozoic time.

Epeiric and shelf seas dotted; oceans ruled. Fresh-water deposits with land life in solid black; these areas, however, have the combined Cenozoic formations. Volcanic regions indicated by crosses.

Note that all geosynclines have vanished excepting remnants of the Pacific one; also that North and South America are separated by the Panama portal, at the time of the greatest submergence of Antillis (Map 2).

formations above the Eocene reach 2500 feet in depth, and in that state the Oligocene is profuse in invertebrate life.

In the *embayment of the Mississippi valley* extending to southern Illinois occur only Eocene fresh- and brackish-water sands and clays, with beds of lignite (see Pl., p. 593), the plant accumulations of former swamps. These are the sediments of the ancient delta of the Mississippi River when the shores of the Gulf of Mexico were at Cairo, Illinois. Later, in early Oligocene time, the sea had withdrawn to middle Alabama (see Pl., p. 593).

Westward from the Mississippi River on the *western Gulf Coastal Plain,* the older Eocene is well developed into Texas and northern Mexico, while the younger Eocene is not known west of the Red River of Louisiana but is again sparingly present in northeastern Mexico. These marine, brackish-water, and swamp deposits of sands, clays, greensands, and lignite beds attain to a maximum thickness of 2000 feet. Since Oligocene time the great stream of fresh water from the Mississippi River has not only had its influence on the sedimentation of this area, but has also prevented the intermigration of the shallow-water life to the east and west of the river.

The Oligocene formations are well developed in Louisiana, where they are essentially fresh-water sands and green clays, reaching a thickness of 1600 feet. In Texas these strata are practically unknown, but in Mexico they occur as narrow overlaps. West of the Mississippi River Miocene strata are known only in deep wells, and at Galveston, Texas, they are 2300 feet beneath the surface, showing the extent to which the eastern margin has been warped beneath the sea since late Miocene time. Of Pliocene strata there is but a small development in Mexico. (See Pl., p. 593.)

There are no marine deposits of the early Eocene known in *Central America,* and hence we may assume that at that time and during the late Cretaceous North America and South America were united by a *land bridge* wider than the present one. This connection permitted the land life of the two continents to intermigrate. During later Eocene time, however, and more especially throughout the Oligocene, the Caribbean Sea spread widely across southern Central America and some of the Atlantic Eocene molluscs migrated to California and South America. During the earlier Miocene the two continents still remained separated, and they were not reunited until late Miocene time. Even though the Central American land was wide, the land bridge does not appear to have been a favorable one for intercontinental migration of land animals. This may have been due to the mountainous and volcanic nature of the region, but more

probably to the barrier of the tropical jungle. The Caribbean did not again invade this land until Pliocene time, and then only marginally. (See Pl., p. 593.)

The *Greater Antilles*, Cuba, San Domingo, and Porto Rico appear to have been large land areas during the earlier Eocene, and it further seems that Cuba was then connected with Central America. In the Oligocene, however, all except the mountainous central portions of these islands were beneath the sea, whose waters were tropical and abounded in a very varied life. The record begins with local shallow-water formations of dark to black shales and ferruginous sandstones up to 1000 feet thick. These are followed by the widely spread white foraminiferal limestones and marls varying in depth from 700 to 2600 feet. From this it appears that it was during the Oligocene that the oceans most widely flooded the Antilles and Central America.

Elevation of the Antilles again took place early in the Miocene, but it is not yet established that Cuba was then or at any time subsequently in connection with Central America. The living native mammals of the Antilles are small, of but a few kinds, and of ancient types. None of the larger North or Central American mammals appear to have reached these islands. In the Pleistocene of Cuba, however, there are several species of ground-sloths that Matthew believes are all derived from a single small form thought to have drifted there on a natural raft across the Caribbean from South America. For the earlier history of Antillis, see page 570.

Seas with Pacific Waters. — Almost all of our knowledge of marine Cenozoic invasions along the Pacific is restricted to the states of California, Oregon, and Washington, and northward into the Vancouver area of Canada. There appears to be no sedimentary record along the shores of British Columbia and Alaska until late in Miocene times, and even this marine overlap was of small extent (see Pl., p. 593).

In most places the Cenozoic rests unconformably upon the Mesozoic or older rocks, though at times the contact is a disconformable one. In California there are other unconformities in the Miocene, and at the close of the Pliocene. Arnold states that about 25,000 feet of strata were accumulated during the Cenozoic, but if we take the maximum thicknesses for all the formations the total rises to about 45,000 feet. In the main the deposits are coarse detritals, as sands, muds, and much volcanic ash with local lava flows. The seas were shallow and in places became filled with sediment and then passed into marshes, making coal beds, as was especially the case in the estuary of the Puget Sound region, where 125 coal beds occur. The times of most marked and general sedimentation were in the early Eocene (8000 to 12,000 feet) and the late Miocene (8000 feet in California). In the Pliocene and Pleistocene, 13,000 feet of sands and volcanic materials were laid down south of San Francisco.

Throughout Alaska and extending into British Columbia occurs the widespread Kenai formation of continental character, which has a maximum thickness of 10,000 feet. It has much plant material and many beds of lignite, with some marine animals that indicate the age to be Eocene.

It is not yet clear to what extent during the Cenozoic Alaska was united with Siberia, though it seems that the ocean did not invade the Bering Strait region until late in Miocene times. If this land bridge between Asia and America was not in continuance throughout all of this time, it was during most of the era. Since the Pliocene the bridge has been crossed by the sea at different times, though at no time was this very shallow sea much deeper than it is now.

Continental Deposits of the Rocky Mountains. — Fresh-water and eolian deposits of Cenozoic time cover great areas in the United States, chiefly in the foothills and the plains country east of the Rocky Mountains (see Pl., p. 593, Map 1). It should be clearly understood, however, that the deposits consist of a large number of separated formations, laid down by many large and small rivers over their flood plains, now here and now there throughout the Cenozoic. As a rule, the strata remain horizontal and are somewhat consolidated into sandstones, sandy shales, and local conglomerates. Volcanic ash in thick beds or reworked by water and wind occurs in most of the formations and constitutes a considerable amount of the Cenozoic rocks of the plains country. Nearly everywhere the strata are exposed to view in more or less locally dissected places where the rain, streams, and wind of the present semiarid climate have worn them into those picturesque areas known as "bad-lands" (see Fig., p. 35 of Pt. I). The thickness at any one place varies from a few hundred feet to several thousand but if all the thickest local deposits are combined the total Cenozoic sedimentation attains to well over 20,000 feet. It is in this vast mass of material that lies buried the most interesting known record of mammalian evolution, the remains of one organic dynasty after another, whose histories have attracted the attention of paleontologists the world over.

The older geologists stated that these strata had in the main been laid down in lakes of vast extent. During the past twenty years, however, it has been shown that they are the materials of rivers originating in the mountains, and meandering and unloading over great flood plains under a more or less semiarid climate. In addition there is also a great deal of wind-borne material, desert dust, and fine volcanic ashes from the western volcanoes, that at times killed and buried the flora and fauna over considerable areas. This ash came in greatest mass during the Eocene, Oligocene, and Miocene.

The Unfolding of Cenozoic Events in North America

Eocene Epoch. — Eocene time is the first and the longest enduring of the Cenozoic epochs. It is out of the life of this time that the present organic world dawns, with the degree of organic progress most marked in the marine molluscs and the land mammals. While many genera of Mesozoic origin continue into the Eocene, none of the marine species do. This marked break in the continuity of the organic world is explained by the absence of strata connecting these two records. The marine break is longest, and in England and America the lost record may be as long as the whole of Cenozoic time. In the fresh-water deposits the hiatus is far less but nowhere is there a complete transition.

In the Eocene marine faunas, there are at no time more than about 5 per cent of living species, and therefore the dawn of the Recent

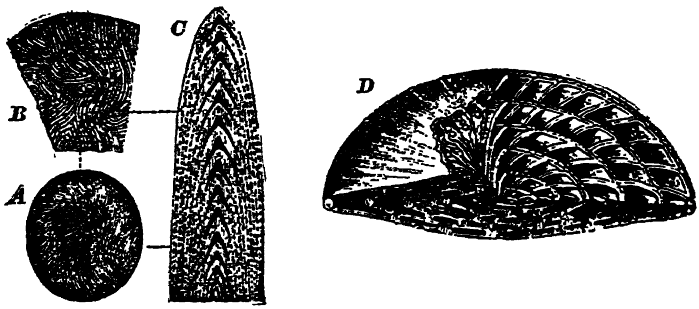

Fig. 205. — Foraminifera (*Nummulina*) in large colonies, from the Eocene of Egypt. *A*, colony, nat. size. *B*, surface enlarged to show canals. *C* and *D*, portions enlarged to show individual cells or chambers. From Steinmann's *Einführung in die Paläontologie.*

is not yet marked. In late Eocene time the mediterranean Tethys was of very wide extent and its warm waters swarmed with shell-making and ground-living Foraminifera, the latter comprised under the term nummulites, because of their resemblance to a Roman coin (*nummulus*). The limestones made by these little animals are in places several thousands of feet thick and furnished the building stone for the pyramids of Egypt.

After the deposition of the latest Mesozoic fresh-water deposits (Fort Union, Puerco, and Torrejon), uplift combined with much volcanic activity followed in the area of the Rocky Mountains. In consequence there resulted in the plateau area during the earlier Eocene a long deposition of intermontane continental formations (Wasatch, Wind River, Green River, and Bridger). They cover an area 450 by 250 miles and vary in thickness from 2400 to over

10,000 feet, the greater part of which consists of ash and coarse igneous detritals. They have a marvelous record of successive mammal faunas.

Green River lake of middle Eocene time, covering at least 350 by 150 miles, was shallow and lay near sea-level. Many of its deposits are bluish black in color and abound in petroleum that will some day be distilled from them. From these deposits have been described 80 species of plants (palms, figs, planes, etc.), 280 kinds of insects, 35 fishes, one of which is 6 feet long, and the complete skeleton of a bird. Among the fishes are 8 kinds that are clearly of the sea, showing that they got into this lake to spawn by migrating up some unknown river. One of them is a sting-ray.

In the latest Eocene (Uinta) the formations are much thinner, averaging about 3000 feet. These various Eocene deposits are best developed in western Wyoming, eastern Utah, and western Montana. In them lies buried the most wonderful record anywhere of archaic mammals, hold-overs from the Mesozoic world, together with an unfolding sequence of modernized animals. Where these heralders of the Cenozoic came from is unknown but it is thought most probably from Asia. All through the Eocene there is contest between the native and immigrant mammals for the habitats, and the supremacy is seen to lie with the latter, due to their greater mentality. At first there was free migration with Europe but after Wasatch time the interchange soon ceased. The succession of these mammals is described in detail in the next chapter.

During Eocene time the holarctic continent *Eris* (see Fig., p. 555) permitted wide radiation of its land life east and west throughout Eurasia and North America. The same appears to be true for a greater Antarctis, which connected not only with South America but seemingly with Australia as well. North and South America were also united toward the close of the Mesozoic and during much of the earlier half of the Eocene.

Oligocene Epoch. — The Oligocene was the warm time of the Cenozoic and the lands were peneplained through erosion to their least elevation above sea-level. The streams meandered widely and the climate during the earlier and greater part of the epoch was in most places moist and therefore continued the general prevalence of forests with the kinds of trees like those of the Eocene. Hence most of the mammals were still browsers. The last of the large and diversified crocodiles lived then.

The White River fresh-water deposits of sand and ash of the Rocky Mountains area are of wider distribution than are those of

the Eocene, occurring in Nebraska, North and South Dakota, Wyoming, Colorado, and Montana. They are also much thinner, not averaging much above 500 feet in thickness, but are most important for the mammals they contain. In Oregon are other deposits of this epoch, the John Day intermontane formation, consisting largely of from 3000 to 4000 feet of volcanic ash and tuffs, and also yielding many mammal remains. During White River time there was again interchange of mammals between America and Europe.

Oligocene *marine life* is particularly well developed in the Gulf States east of the Mississippi River and in the Antilles, but along the Atlantic border there are no Oligocene deposits at all. In the Gulf area it is warm-water life, profuse in molluscan species, and abounding in reef-making corals, but the dawn of the Recent is not even yet strikingly at hand, since in the life of this time there are not over 15 per cent of living species. Florida appeared in late Oligocene time as a small island, and has been a peninsula since the Pliocene.

Miocene Epoch. — The marginal seas of Miocene time were not large along the Atlantic and Gulf States, but in the Californic geosyncline there is a long record in very thick deposits, made up largely of ash and the siliceous tests of microscopic plants, the beautiful diatoms. The dawn of the Recent is now strikingly at hand, since nearly one half of the molluscs are of kinds still living. The Atlantic waters were cool and this is best shown in the Chesapeake formation, known to extend all the way from Massachusetts to Alabama. These cool waters with their life came from the Arctic Ocean, and indicated that the old holarctic land Eris had been broken through between Greenland and Norway in about Middle Miocene time. This letting of cold waters into the Atlantic, Dall says, brought on the most marked change of any in the marine Mollusca of Cenozoic time (see Fig., p. 609).

In the Rocky Mountains area, elevation was again going on, resulting in drier and cooler climates. Volcanoes were numerous and active. The fresh-water formations are many (Arikaree, Harrison, lower Loup Fork, Clarendon, and Deep River), there is also more ash again present, and the grain of the strata is coarser in the west and finer in the east, proving their western origin. The thickness of the formations varies between 400 and 2300 feet, with the main areas of deposition in Nebraska, Kansas, and northeastern Colorado. In these deposits there is also a great array of entombed mammals, and there was another interchange of them with Europe

in Deep River time, when primitive elephants came from Asia. There was also renewed intermigration with South America in late Miocene time.

About Florissant, Colorado, there was a lake in the later Miocene, surrounded by active explosive volcanoes. The ashes from them fell into these waters, entombing a known flora of 250 species, and more than 1000 kinds of beetles, ants, flies, and other kinds of insects. Other Miocene lakes existed in southwestern Colorado.

The climate in Miocene time became drier, and the forests, in consequence, more greatly reduced in areal extent. The grasses took possession of the open spaces, and these changes in the plant world revolutionized the food conditions among the herbivorous mammals.

In Middle Miocene time intermigration was again established between America and Asia, and the rhinoceroses and the long-faced elephants spread into the New World. About this time or more probably later, intermigration again took place with South America, and this interchange was greatest during the Pliocene epoch.

Pliocene Epoch. — During the Pliocene, North America was more emergent than at any other epoch of the Cenozoic, and there is therefore but little of marine life to describe. Elsewhere it is seen to be very much like that of the present.

In the Rocky Mountains, Pliocene formations (upper Loup Fork, Blanco) are widely scattered but of limited extent, and they are not very well understood. The whole of the Cordilleras were being elevated and in consequence the climate became more arid and much cooler. Most of the larger mammals were exterminated, but those of the earlier Pliocene closely resembled the ones living to-day in central Africa.

The *Pleistocene* epoch was a critical time in the organic world, the balance being disestablished by a very cold climate, but in all of this adversity man arose to take possession of the earth. What these conditions and changes were will be described in two subsequent chapters.

Life Characteristics in North America

The Cenozoic is the *Age of Mammals* since they are present in greatest variety and number and dominate the life not only of the lands but as well of the seas and oceans. In the later Eocene occurs the first mammal adaptation to an oceanic life, in the form of whale-like animals (*Zeuglodon*). In the Oligocene came the sea-cows, and in the Miocene the true whales, seals, and sea-lions. The

evolution of the mammals and their kinds are described in special chapters following this one.

The toothed *birds* vanished with the Cretaceous, and with the Eocene began the evolution of the modern kinds. Most of the living birds trace their ancestry back to the Eocene, and in this epoch a conspicuous element was the flightless land-living birds resembling modern ostriches. More detail as to the Cenozoic birds will be found in Chapter XL.

The wonderful *reptile* development of the Mesozoic is nearly all gone in the earliest Eocene and at no time during the Cenozoic did these animals play a conspicuous rôle. Turtles, alligators, and crocodiles are of largest growth in the Oligocene, while lizards and snakes become decidedly more varied and live in all of the warmer habitats. The venomous snakes originated after Eocene time.

The *land floras* of the Cenozoic had arisen in the Cretaceous and the woody trees and bushes were much like those of the present. The grasses and cereals, originating late in the Cretaceous, did not take full possession of the open places until Miocene time, and then their abundance led to much adaptation and evolution among the herbivorous mammals. The palms were especially abundant in the first half of Cenozoic time, and throughout this era the sequoias were of world-wide distribution. To-day but two species are living in isolated areas in California, where some of the individual trees are known to have attained an age of upward of 3000 years.

More than six thousand species of Cenozoic *insects* are known, and it may be said that the fullness of insect life was attained in the Miocene. Ants are very old animals, and their origin appears to go back to Jurassic or even earlier times, although the oldest known fossil forms are found in the Lower Oligocene ambers of the Baltic region. Wheeler has determined about one hundred kinds of ants in these ambers, of which twenty-four are still living. See also page 515.

In the seas and oceans of Cenozoic time, the shelled *molluscs* attained their greatest progression in variety and numbers, and it is this evolution that is at the basis of Cenozoic chronology. Of the grand array of Mesozoic ammonites not a single one passed into Cenozoic time. The bivalves were particularly common and modern, and prominent among them were the many kinds with large siphons, the shell being buried in the mud. Oysters attained their climax of development in the Miocene of California, where the giants had a length of 13 inches, a width of 8 inches, and a depth of 6 inches.

Corals in the Cenozoic were not more conspicuous than they are now, and the variety no greater. Finally, attention should be directed to the wonderful array of living *crabs*, which had their origins in the many forms of the Oligocene and Miocene.

Climate

In the area of the Rocky Mountains, David White states that the climate toward the close of the Cretaceous (Laramie) was as warm as at present along the Gulf of Mexico. Later (Fort Union) the temperature was cooler, with distinct winters like those of the present Dismal Swamp of Virginia. During early Eocene (Wasatch and later) the climate was cool and semiarid.

Atwood in 1913 discovered at a number of localities in the San Juan Mountains of Colorado beds of *tillites*, ranging in thickness from 80 to 100 feet. The material was derived from high mountains fully 40 miles away, which then stood to the south and southeast of the present till areas. The tillites unconformably overlie the Cretaceous and are covered by Eocene tuffs, indicating a probable early Eocene age. It is to be expected that other areas of these tills will be found, in which event it will appear that the Laramide mountains were then widely covered by alpine and piedmont glaciers.

Blackwelder and Sayles have shown that the early Eocene shales of Green River age are distinctly banded, and this strongly suggests seasonal deposition. Toward the close of the Eocene, however, according to White, the floras of even arctic lands show the return of mild climates, as mild as that of the present Gulf States. Along the Yukon then lived cycads, magnolias, firs, and delicate ferns.

It has long been recognized that during the late Eocene and all of the Oligocene there were world-wide genial climates. Furthermore, up to the close of the Oligocene the climates of North America were moist and the lands lay near sea-level. With the Miocene, however, the lands in many parts of the world began to rise into mountains, and gradually the climates became cooler and drier. More or less of desert climates developed in the Cordilleran areas of North America and have prevailed there ever since. In the Miocene, parts of Eris foundered, separating Greenland from Norway and Scotland, and colder waters spread all along the Atlantic shores of North America. This evidence is recorded in the Chesapeake formation which, according to Dall, has a cool-water fauna. The climate continued to grow cooler, and in the Pleistocene occurred one of the two most marked glacial climates known to geologists, described in Chapter XLV.

PART II. MOUNTAIN MAKING AND ORIGIN OF PRESENT SCENERY

Cascadian Revolution in North America. In the chapter on the Cretaceous it was stated that the Mesozoic era in North America was closed by the Laramide Revolution, when the Laramide mountains (practically the Rocky Mountains) were folded and thrusted toward the east (see p. 567). This orogeny, however, was not all of one time, since the first movement came just before the deposition of the Fort Union formation, followed by a long quiescent time and the laying down of these sands and muds. Then at the close of the Fort Union took place the final and greater movement of the Laramide mountains. Eruptions, mainly of an explosive character, continued, though with diminishing force, throughout Eocene and Oligocene time, but the earth-shell remained fairly stable, enabling the atmospheric forces to reduce greatly the high elevations of the Laramide mountains.

In Middle Miocene time the Pacific States were again in the throes of mountain making, and igneous eruptions became active, with the formation of highlands in eastern Washington and Oregon, and at the same time came the second period of elevation of the Coast Range of California (see Pl., p. 593, Map 3). It is interesting to note here that the great San Andreas earthquake rift of California, which extends for 600 miles southeast into the Mohave desert, had its origin at this time.

At the close of the Pliocene or early in the Pleistocene, the Sierra Nevadas were elevated bodily from 5000 to 7000 feet and they are still going up. They are a crust block 300 miles long and 50 to 60 miles wide, greatly elevated on the eastern side, forming there a great fault with from 15,000 to 20,000 feet of vertical displacement.

During the Miocene, decided folding and faulting with volcanic activity also occurred in the Isthmus of Tehuantepec of southern Mexico, in Central America, and apparently throughout the West Indian islands. Finally, it may be said that especially during the Miocene, and less in the Pliocene, the entire area of the overlaps of the Pacific Ocean in North America (see Fig., p. 609) was being elevated, folded, faulted, and thrusted into the Pacific System of mountains. During the later Pliocene, the entire area of the Rocky Mountains and especially the plateau region of the Colorado River were further vertically elevated several thousand feet.

Eastern North America was also elevated at this time, but how much is not yet determined, and the entire Mississippi valley was raised several hundred feet, or to its present elevation. Generally

speaking, the close of the Pliocene must be regarded as a time of great deformation, bringing on the critical period in North America during Pleistocene time.

Origin of the Gulf of St. Lawrence. — The St. Lawrence River below Montreal appears to be very old, and the antecedent river was seemingly older than the time of the reëlevation of old Appalachis at the close of the Mesozoic. The course of the river then, as now, was conditioned by the nature and the southward slope of the hard crystallines of the Canadian Shield to the northwest and the much softer crumpled Paleozoic strata to the southeast. Furthermore, the Appalachian strata are thrusted over the crystallines and the river therefore naturally follows the line of weakened rocks, the Champlain overthrust or "Logan's line." The outer portion of the old river valley lies between the headland of Gaspé and the island of Anticosti, and, as Clarke points out, Logan's line in Gaspé is deflected southeastward and with it the ancient river valley. Farther southeast it has cut itself through the Appalachian folds and the river flows through what is now Cabot Strait into the Atlantic between Cape North of Cape Breton and Cape Ray of Newfoundland. All of this is well shown on the Admiralty charts. Far to the southeast of Newfoundland, in the area of the fishing banks and beyond, lies the deeply submerged delta of the St. Lawrence. This is something of the history of the river, but the subsidence and the origin of the Gulf of St. Lawrence appear to be of very recent date, of latest Pleistocene time, since no older marine fossils are known along its shores. In any event, the faulting now seen off western Newfoundland and the subsidence of the gulf are of Pleistocene origin. The amount of this subsidence is at least 600 feet and in latest Pleistocene times it was over 1200 feet. (See J. M. Clarke 1913.)

Origin of the Gulf of California. — There is no evidence throughout Mesozoic time of the Gulf of California. In late Eocene time (Claiborne) marine waters began to overlap the southern end of Baja California, and we may conclude that the inbreaking of the Pacific and the formation of the ingression gulf began early in the Eocene.

The foundering of the lands into the gulf was most extensive during the early Miocene, when marine waters (Carrizo Creek) extended into southeastern California, as far north as the San Bernardino Range. These marine waters of Miocene time teemed with corals, oysters, and numerous other kinds of shells, which in many places in the Colorado desert are strewn over the ground. Even more interesting is the fact that many of these marine animals are of Antillean (Bowden) kinds, showing plainly that the portal of Tehuantepec was again open to the interchange of waters from the Gulf of Mexico and the Pacific Ocean.

Later, when the sea retreated, the Colorado River flowed into the gulf, but it was not until the Pleistocene that it cut deep canyons, became loaded with conglomerates, sands, and muds, and filled in the head of the Gulf of California with a mighty delta. The present deepest part of this land portion of the gulf is in the west between the San Bernardino and San Jacinto mountains to the north of the Colorado desert. This was the bed of the old Salton Sea, which was again partially filled with the waters of the Colorado River in 1893 and 1907. John C. Van Dyke in his most interesting book, *The Desert*, calls this area "the Bottom of the Bowl." "When you are in the bottom of it," he says, "you are nearly three hundred feet below the level of the sea. Circling about you to the north, south, and west are sierras, some of them over ten thousand feet in

height. These form the Rim of the Bowl. And off to the southwest there is a side broken out of the Bowl through which you can pass to the river and the Gulf. The basin is perhaps the hottest place to be found anywhere on the American deserts. And it is also the most forsaken."

Emergence of American Scenery

In general we speak of the "everlasting hills," and yet Geology teaches that time and again mountains have been raised and worn away. At present many lands are famous for their majestic snow-covered mountains and glaciers and beautiful hill country. Northern lands are studded by innumerable lakes that came into existence with the Pleistocene. All of this elevated scenery is destined to be worn away and the former highland areas leveled into plains that will continue unbroken into those of the more extensive nuclear or shield regions. The latter have been undulating plains since the Cambrian, and but little above sea-level. In all of this we see that the times of beautiful scenery and land sculpture are of very short duration and that during by far the greater part of geologic history the lands were monotonous in their flatness. Now let us take up a study of this subject according to the topographic regions of North America.

Interior Lowlands. — The Mississippi River lies in the center of the Interior Lowlands and the Gulf of Mexico portion of the Coastal Plain. Most of this area is underlain by horizontal strata. To the north it passes into the vast upland of the Laurentian Shield, made up of the most ancient and most deformed rocks. The Gulf Coastal Plain is at best but a few hundred feet above sea-level and in Canada the Laurentian Upland will average between 1000 and 2000 feet above the sea.

Nearly everywhere in these lowlands the rivers, inside of the coastal plains, lie in entrenched valleys, showing that these plains have recently been raised, or better, differentially warped, to a higher level which within the United States does not exceed several hundred feet. This warping took place during the Pleistocene and Pliocene. Back of this time, in the earlier Cenozoic, these plains stood at the lower level, and the greater central portion appears to have continued so back into Mesozoic time. Hence the Interior Lowlands and the Laurentian Upland have been plains ever since the close of the Paleozoic, and in general their surfaces throughout this vast time have been eroded to a depth of not more than a few hundred feet.

Appalachis. — Toward the close of the Mesozoic, the Interior Lowlands continued unbroken across the Appalachian Plateau and

the Appalachian folded land, into the eastern Coastal Plain. Then at the close of the Mesozoic and during the Cenozoic, this previously folded area was bodily, and at different times variably, elevated up to a total of about 2000 feet above sea-level, and this all the way from Alabama across Newfoundland. With this elevation came also the making of the lateral monoclines, the narrower Piedmont Plateau in the east and the wide Appalachian Plateau on the west. On these elevated plains ever since the Cretaceous the grinding antecedent rivers have been at work entrenching themselves in deeper and wider valleys. In them the scenery is beautiful, walled in as they are by the youthful mountains on either side, but when one rises to the highest of their flat table-like tops one looks across the old peneplain of Mesozoic making. The scenery of the valleys is therefore of Cenozoic origin, and in most of them there is a stair-like series of elevated river terraces, each rising from one to several hundreds of feet, proving the periodic elevations of the region.

Rocky Mountains and Great Plains. — In Mesozoic times the Interior Lowlands continued westward, at about the same general level, to what is now the westernmost Rocky Mountains. Then at the close of the Cretaceous came the making of these mountains and their subsequent erosion into depressed and rounded hills that melted away eastward into the Interior Lowlands. Therefore during the Oligocene the interior of North America was one vast and nearly featureless peneplain. Then in the Miocene the internal forces of the earth began to reassert themselves, and during the Pliocene and Pleistocene the area of the Rocky Mountains was raised bodily to its present altitudes. With this elevation also came into being the present vast monocline of the Great Plains that in the west stands more than 7000 feet above sea-level and in the eastern Dakotas, Nebraska, Kansas, Oklahoma, and central Texas passes into the low level of the Interior Lowlands.

Pacific Area. — The western margin of North America in the Middle Miocene again began to fold and rise into mountains, giving rise to the Pacific System. Great volcanoes then grew on the tops of these mountains and there are eleven areas of them between southern Mexico and Alaska. These mountains of fire were most active during the Pleistocene and the grandest of them in this country are Rainier (14,526 feet above the sea), Shasta (14,380 feet, see Pt. 1, Fig., p. 195), and Lassen (10,347 feet); in southern Mexico, Popo (Popocatepetl, 17,500 feet), the White Woman (Ixtaccihuatl, 16,900 feet), and Star (Orizaba, 18,250 feet).

Yellowstone Park. — The Rocky Mountains also had their volcanoes and one of the most scenic and significant of these volcanic regions is the Yellowstone National Park, with its many hot-water geysers (see Pt. I, pp. 230, 231). Here during Pliocene time the volca-

Fig. 206. — Miocene tree trunks of the Fossil Forest, Yellowstone Park, Wyoming. Photograph by J. P. Iddings, U. S. Geol. Surv.

noes in their periodic outburst of ashes buried forest after forest, and many of the trees, since changed to stone, but still standing upright, may be seen in superposed levels weathering out of the rocky sides of the hills (Fig., above).

Great Basin Deserts, and Columbia Plateau. — At the close of the Pliocene, or early in the Pleistocene, the Sierra Nevadas were faulted in the east and elevated vertically from 5000 to 7000 feet, and 450 miles to the east the Wasatch Mountains were faulted along their western side and raised bodily to even greater heights. Between them lies the lower land of the Great Basin that throughout the Pleistocene, as now, was the area of the Great American Desert. To the north of this basin country in eastern Washington, most of Oregon, and western Idaho, is the high Columbia Plateau, through which run the long and entrenched Snake and Columbia rivers. The plateau covers an area of over 250,000 square miles, five times greater than the state of New York. The greater part is a lava plain, since during the Pliocene deep fissures opened here and out of them welled time and again molten rock that finally attained to a maximum depth of 5000 feet (Fig., p. 546).

Colorado Plateau and Grand Canyon. — Between the Wasatch Mountains and the Front Ranges of the Rockies lies the highly elevated Colorado Plateau. This attained its present altitude late in the Pliocene and then began the making of the most scenic of all river valleys, the canyons of the antecedent Green and Colorado rivers and their tributaries. The gorge of the Grand Canyon of the Colorado is in places a mile deep, and its walls of horizontal strata furnish the finest exposure anywhere of the succession of Paleozoic sea bottoms, which in turn rest upon the oldest of the earth's rocks (see Frontispiece).

Conclusions. — In all of this we see that the grander scenery of the present highlands is young, and indeed that most of it has come into being since the Pliocene. The valley scenery of the uplands on either side of the mountains is also young, but the elevated inclined plains above the entrenched valleys are older, and vastly older still are the immense inland plains. These great plains reveal to us a topographic form that was not unlike that of Mesozoic time. How vastly different the life is upon them now, and what majestic brute and floral dynasties have had their being upon them we shall learn in other chapters of this book.

Mountain Making in Foreign Countries

In *South America* toward the close of the Cretaceous the Andes had been elevated, folded, and thrusted eastward throughout the length of the continent (4500 miles), and during most of Cenozoic time an extensive peneplain was being developed in the Central Andes. From the present topographic development of the Andes,

Bowman concluded that vertical uplift began in latter Cenozoic time, elevating this peneplain from 3000 to 7000 feet. This was in turn eroded to mature slopes and then was reëlevated in Pliocene and early Pleistocene time, so that now the deeply dissected erosion surface of the old peneplain stands at an average elevation of 12,000 feet, though locally it varies between 6000 and 15,000 feet. This plain is now the Altaplanici, the high plains of Bolivia. Upon it in the west rest immense lava flows and lofty volcanic cones, some of which attain a height of 21,000 feet above the sea.

Subsequent to Bowman's work, Singewald and Miller (1915) collected at Potosi on the Altaplanici fossil land plants. These

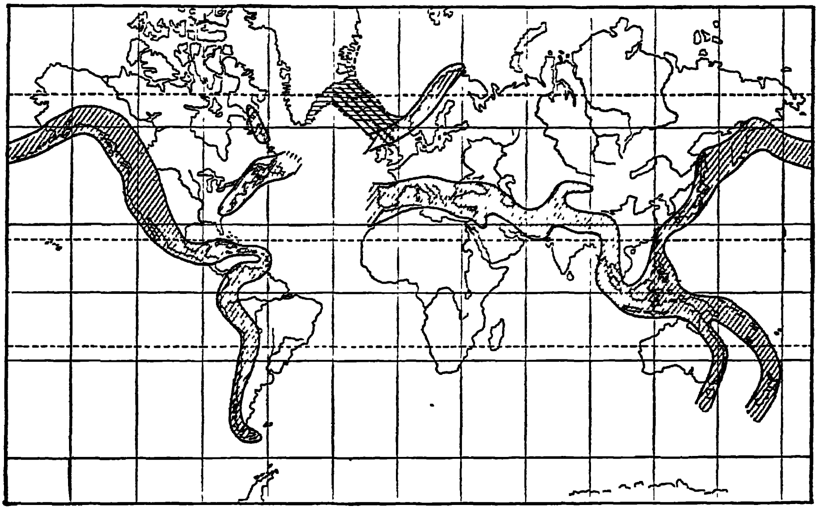

Fig. 207. — Areas of dominant folding and uplift (oblique shading) during the Cenozoic. Horizontal shading, the fractured and down-sinking area of Eris; northwest-southeast lines, the general direction of fractures and dikes.

show that the deposits are of late Pliocene age, and Berry says that the plants could not have grown at a higher altitude than from 4000 to 6000 feet. With this evidence the conclusion is now drawn that the Andes were elevated in Pleistocene time at least from 6500 to 8500 feet. This elevation was accompanied by great volcanic activity in the western ranges. The bulk of mineralization also dates from this time (Berry and Singewald 1921).

Eastern Greenland and the region eastward across Spitzbergen, Norway, Sweden, and Finland (*Fennoscandia*) were subject to great block faultings and warpings, seemingly in late Miocene time, developing not only great rifts or graben but broad sinking areas as

well, with a general trend to the northwest and southeast. This was the time when Eris was broken through, separating Laurentis from Baltis (Fig., p. 609). Previous to the Middle Miocene this land was the bridge that enabled the mammals of Europe and North America to intermigrate. Periodically, but more especially during the late Eocene and Oligocene, lava (the Thulean basalts) flowed widely through fissures over all these lands, and over eastern and western central Greenland, Iceland, the Faroe, Orkney, Shetland, and Hebrides islands, western Scotland, England, and northern Ireland (Giant's Causeway); also Jan Mayen and Franz Joseph islands. The foundering of the crust where the Norwegian sea now is, permitted the triumphant spread of the Atlantic into the Arctic Ocean.

On page 547 it was stated in regard to *Gondwana* that Africa was separated from South America in Lower Cretaceous time (Fig., p. 555), and now we learn that in the Eocene the remainder of this equatorial Atlantic bridge sank, since late Eocene deposits are general along the western border of Africa. The Cretaceous remnants of Lemuris also almost all sank beneath the Indian Ocean during the Cenozoic.

In *Europe*, the majestic Alps are mute evidence of the great unrest of the earth's crust during the Cenozoic, their upward culmination taking place in the late Miocene. The movement began in the west late in the Eocene, when the Pyrenees of Spain, the Rif Mountains of Morocco, and the Apennines of northern Italy had their origin. The entire Alpine system of western Europe began to rise early in the Miocene, and this deformation was most active late in the same epoch and was completed early in the Lower Pliocene when these mountains stood at their highest. The Eocene nummulitic limestones of the Alps are still found 10,000 feet above the sea, and those of the Pyrenees 11,000 feet. The movement was both vertical and thrusting from the south and southeast, from the southern portion of Tethys, elevating and folding the Cenozoic and older strata of the northern areas of this mediterranean into overturned, recumbent, and nearly horizontal folds, and pushing the southern or Lepontine Alps about 60 miles to the northward into the Helvetic region. Erosion has since carved up these overthrust sheets, leaving remnants lying on foundations which belong to a more northern portion of the ancient sea. Most noted of these residuals of overthrust masses is the Matterhorn, a mighty mountain without roots, a stranger in a foreign geologic environment. The thrusting was felt as a warping as far northwest as London, for the basins of London and

Paris date from this time. The Caucasus Mountains of eastern Europe, between the Crimea and the Caspian Sea, are also of early Pliocene origin, for their Miocene strata are now 6500 feet above the sea (see Fig., p. 609).

Wadia states that the Himalayas of *India*, as early as the Middle Cretaceous (Cenomanian), began blotting out in Asia much of the former extent of Tethys. In middle Upper Cretaceous time there was much volcanic activity in these mountains. At the close of the Eocene, however, all of the Tethyian area of the Himalayas and Burma began to fold, giving rise to mountains of considerable altitude in many regions, and yet not extensive enough to blot out the sea. During the Oligocene, Tethys, even though shallow, still preserved its continuity, accumulating thick, uniform marine deposits of gray to greenish shales and calcareous sandstones (Flysch of Swiss geologists). Toward the close of the Middle Miocene, the second and more marked phase of folding began, changing Tethys into a series of disconnected but subsiding basins, accumulating the continental deposits known as the Siwalik clays, sandstones, and conglomerates. Finally, in the Pliocene, came the third and greatest upheaval, when the Himalayas, the loftiest mountains of the earth, had peaks nearly as high as Mt. Everest of the present, which stands 29,000 feet above the sea. The nummulitic limestones of Eocene age are even now as high as 19,000 feet above sea-level, and once extended higher over the mountain axes. This uplift affected the land to the north for 1400 miles into Tibet and Mongolia, and the thrust pushed the older rocks over the newer ones in a north to south direction. (See Fig., p. 609.)

Summary. — In North America the deformation of the Laramide Revolution was followed by a long, almost quiescent time up to the close of the Oligocene. Then unrest made its appearance in the western area of Tethys, and throughout the later half of Miocene and Pliocene time mountain making was going on in most parts of the world, in many areas on a stupendous scale. North and South America with their longitudinal chains of mountains did not change much in outline during the Cenozoic, but Europe, Asia, the Antilles, and Central America, with their latitudinal foldings, underwent marked alteration, and it was in fact in the Pliocene that these continents took on their modern expression. Finally in the Pleistocene the greater part of the Pacific Ocean was margined by majestic volcanoes. "A great line of fire, starting with the early homes of culture in the Mediterranean, belts the earth, and branching grandly in the East and West Indies, cordons the

Pacific like the line of signal fires that flashed the tidings of the fall of Troy across the Aegean to Agamemnon in Mycenæ" (B. K. Emerson).

The Cascadian Revolution of western North America has been of long duration, beginning in the Middle Miocene and continuing into the present time. It is marked by intermittent action, pulsations of vertical uplifts, folding, thrusting, and igneous activity, resulting in new mountain systems, increasing relief, and a higher continent. To us it now appears as if interrupted and finished, because we see it in near perspective. In its entirety, however, it is one of the greater revolutions of the earth, and there is no proof that the end has yet been attained. Long ago LeConte said that the Cascadian Revolution is so recent that the record of it is not lost, and a study of it enables us better to comprehend the changes wrought by the earlier revolutions. In the geologic future it will take its place in the earth record through the evidence of its great foldings, metamorphism, and wide erosion of the older record — a transformation comparable to that wrought by the Appalachian Revolution closing the Paleozoic.

The closing revolution of the Cenozoic era was a critical period in the history of the earth, and as it culminated in the Pleistocene glacial climate, the conditions were all the more hazardous for the organisms that inhabited the polar and temperate regions of the earth. The warmer parts of the globe were the asylums that repeopled the northern lands, but man, probably arising in Asia even before the Pleistocene, advanced during the Glacial Period from the savage to the civilized state under the influence of cooler and even cold climates. We are now living in a time of rugged lands, obliteration of ancient peneplains, cold polar climates, and marked temperature belts.

Economic Products

Petroleum. — In the Gulf Coastal Plain of Louisiana, Arkansas, Texas, and eastern Mexico, vast quantities of petroleum have been and still are being obtained. Most of it is from the marine horizontal Cenozoic formations, though some comes from undisturbed Cretaceous strata. California is another region that is producing petroleum in enormous quantities from the Cretaceous and the Cenozoic, which are more or less highly folded. The most extraordinary of all Cenozoic oil fields is, however, that of Baku, Russia, situated on the western shore of the Caspian Sea.

The Green River formation of the Uinta Basin, Utah, of Eocene age, has at least eighty beds of oil shale that will yield from a few to at least 55 gallons of oil to the ton, the average being about 12 gallons. It is estimated that there are here at least 42 billion barrels of petroleum and 500 million tons of ammonium sulphate (D. E. Winchester).

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CHAPTER XLII

THE EVOLUTION OF MAMMALS AND THE RISE OF MENTALITY IN THE CENOZOIC

The lands of Cenozoic time were dominated by mammals, and the seas and oceans of this era were not devoid of them. Mammals were, in fact, as characteristic of the Cenozoic as reptiles were of the Mesozoic. It is true that archaic mammals originated as early as the Triassic, but at no time in the Mesozoic era did these small animals take the lead among organisms.

There are now living more than seven thousand kinds of mammals, twenty-one hundred of which are in North America alone. Of fossil mammals, there are known several thousand additional kinds.

General Characters. — Mammals, structurally the highest group of animals, are warm-blooded vertebrates with milk glands. These glands, which vary in number from one to eleven pairs, are the mammary glands or breasts, the structures from which the class has taken its name, for *mamma* means *breast*. They are also present in the males, but are normally non-functional. All mammals are more or less covered with hair, which is as characteristic of them as feathers are of birds.

With regard to the nervous system, the brain in mammals attains the highest degree of development known, and is most markedly convoluted in man. The body cavity differs from that of all other vertebrates in that it is completely divided into two parts by a muscular membrane, the diaphragm, which separates it into a thoracic cavity containing the heart and lungs, and an abdominal cavity containing the remaining viscera. In most mammals there are two sets of teeth, the milk dentition or temporary teeth which eventually fall out, and the permanent teeth which succeed them. The heart is four-chambered as in the other class of warm-blooded animals, the birds, and the course of the blood through it is the same in both. The period of fœtal development or gestation varies from three weeks in some mice to twenty months in the elephant.

Most mammals have a completely terrestrial habitat, while the seals, sea-lions, sea-cows, whales, and porpoises live in the oceans.

One order of wide distribution, the bats, have developed the front limbs into wings, while other stocks have lateral or body membranes between the limbs, and spreading these, glide from tree to tree.

General Classification. — All mammals are separated into subclasses on the basis of the production of the young. In the most primitive subclass, the *Prototheria*, the young are not born alive but are hatched from eggs as in reptiles and birds. All other mammals are classified as *Eutheria*, and they produce living young. Of these the more primitive are the marsupial mammals or

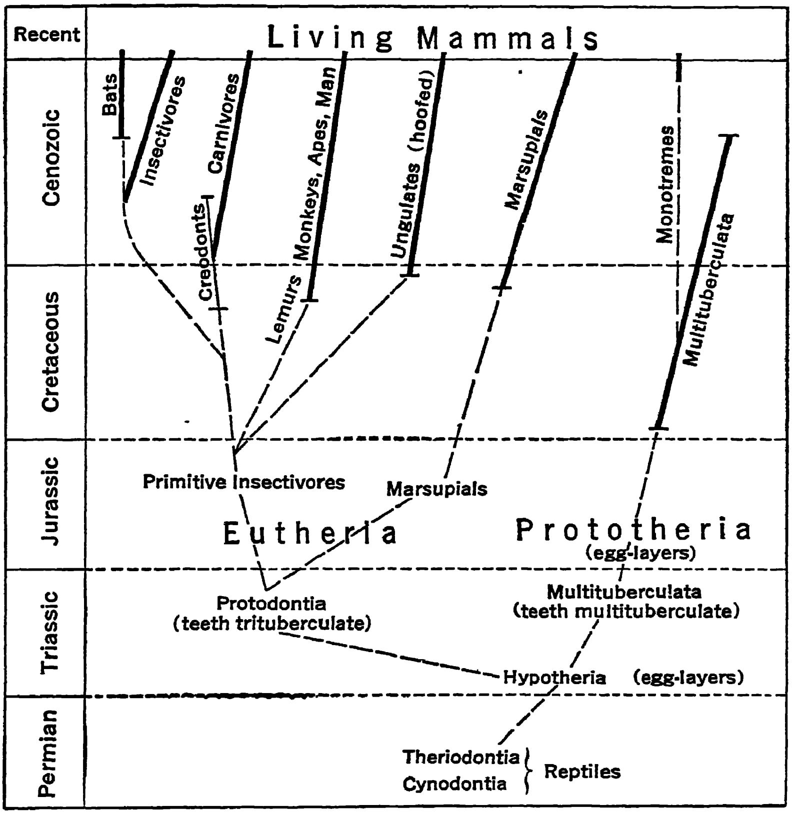

Fig. 208. — Diagram showing the main lines of descent of the mammals in Mesozoic and Cenozoic time. After Osborn.

Didelphia, animals with an abdominal pouch; the young are born immature and are reared in the marsupium. All other Eutheria are the *Placentalia* or *Monodelphia*. The placenta is a special growth, partly of fœtal and partly of maternal origin, in which the young develop during the period of gestation (see Fig., p. 415); the young are born in a relatively mature state.

Origin. — The working out of the evolution of fossil mammals started in Europe early in the nineteenth century, but the rapid acceleration of our knowledge began with the discovery in the badlands of the Great Plains of the United States of the most wonderful succession of bone beds anywhere. The collecting

was begun by F. V. Hayden on the early Government surveys, and the description by the pioneer vertebrate paleontologists Leidy, Cope, and Marsh. Since their time many other workers in America and Europe have added a vast deal of information, so that now our present detailed knowledge of mammal succession throughout the world is very good indeed (see Pl., p. 493).

In presenting the origin and evolution of mammals, we will follow in the main the work of Osborn (*Origin and Evolution of Life*, 1917). Beginning with Huxley, most students of mammals have held that they arose in small tree-living and insect-eating forms, and that the greater evolution took place during the Mesozoic era. The African tree-shrew (*Tupaia*) is considered to be the best living representative of this ancient type of mammal. Proof of the arboreal habitat of medieval mammals is seen in the adaptations of the hind feet for holding on to branches, especially among the ancestral primates.

The earliest mammals of the Mesozoic had their origin in active and more or less tree-living lizard-like reptiles of the Permian (Cynodontia and Theriodontia). These gave rise to egg-laying mammals (the Hypotheria) like the living duck-billed mole and echidna, now restricted to Australia and [New] Guinea, and to an extinct group, the Multituberculata, so named because of the many cones on the grinding surfaces of the molar teeth. These were the common kinds of mammals throughout the Mesozoic, and collectively are known as the Prototheria. Of greatest importance in the higher evolution was the introduction of *warm blood*, which may have been initiated in some of the cynodont reptiles of the Permian (see Figs., pp. 417 and 615).

In the latter part of the Mesozoic arose the pouched mammals (marsupials), forms like the living kangaroos so wonderfully differentiated in Australia. They arose in small tree-living mammals like the present opossums of North and South America. The upwelling of the highest mammals, the Placentalia, also came late in the Mesozoic out of primitive insectivores. Their dominance of the organic world during the Cenozoic was largely due to a longer and better development of the unborn young in the placenta. (Study diagram, Fig., p. 615.)

The placental mammals during the Mesozoic and early Cenozoic differentiated from the primitive insectivorous arboreal ancestors into ten great branches. All, however, were still small-brained and small in size, archaic egg-layers and bearers of pouches. In addition, the mechanics of their skeletons was clumsy.

1. Insectivores
2. Bats
3. Primates
   - Lemurs
   - Monkeys
   - Apes
   - Man
4. Carnivores
5. Seals (marine)
6. Whales (marine)
7. Hoofed mammals
8. Manatees or sea-cows (marine)
9. Rodents
10. Edentates

The nearly universal forest of cone- and flower-bearing trees (soft and hard woods) was yielding space toward the close of the Mesozoic to the herbaceous plants and the grasses that made for a better and more abundant food in the open plains and meadows. With this great change in the plant world there came therefore an increased variety of environments, along with new feeding and locomotor habits. Osborn says that a mammal may seek any one of twelve different habitats in search of food, and that within each one of these there may be six entirely different kinds of subsistence. With the further freeing of these habitats through the

vanishing of the competing medieval reptiles, we see why the mammals burst, as it were, into domination of the lands toward the close of the Mesozoic era. The placental mammals spread into all the habitats, became very varied in adaptive structures and innumerable in individuals, most of the stock increased rapidly in size, and some became giants.

This higher mammalian succession is a wonderful series of evolutions, and if the student wishes to follow it out in more detail than can be given here, he is referred to Scott's *A History of Land Mammals in the Western Hemisphere* and Osborn's *The Age of Mammals.*

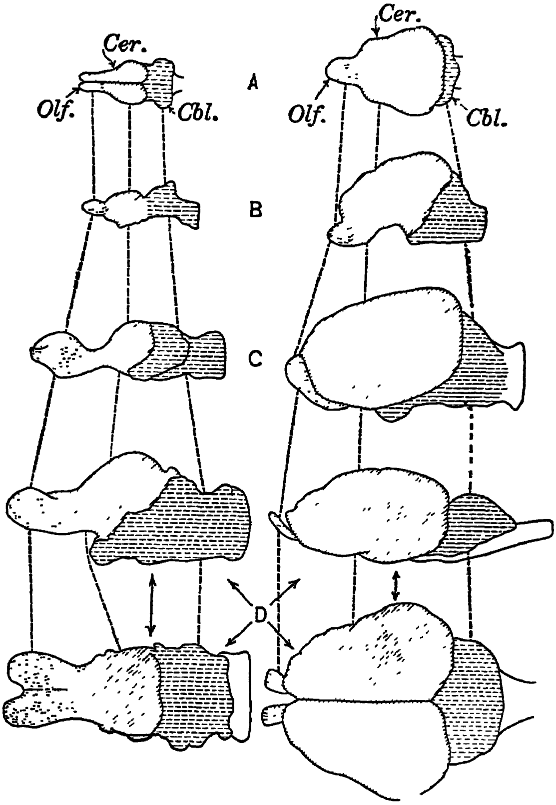

Fig. 209. — Brain proportions in archaic (left) and modern (right) mammals of similar size. *Olf.*, olfactory lobes; *Cer.*, cerebrum; *Cbl.*, cerebellum and medulla. A, *Arctocyon-Canis;* B, *Phenacodus-Sus;* C, *Coryphodon-Rhinoceros;* D, *Uintatherium-Hippopotamus.* From Osborn's *Age of Mammals.*

Increase in Size of Brain. — In the Mesozoic mammals the brain, Lull states, was singularly old-fashioned, generally small, but always relatively undeveloped in comparison with that of modernized mammals of equivalent bulk, especially in the part wherein the intelligence lay, the upper brain or cerebrum (see Fig., above). It was in the

Eocene that the brain in most mammals began to enlarge, so that here it was about one eighth that of living forms of the same stocks, and this enlargement was by far the most striking in the upper lobes. That the brain in mammals increased in size throughout the Cenozoic was first suggested by Lartet in 1858, and demonstrated by Marsh in 1874 and again in 1885. Truly, the Cenozoic was the time of transition from an ignorant world of brutes to the present Age of Reason, the Psychozoic era.

Mammal Succession in North America

The Cenozoic of North America opens with an archaic indigenous mammal fauna, a most curious, strange, and bizarre assemblage. It is plain that it is an advanced and diversified fauna, the descendants of Mesozoic mammals. Later appear unheralded as migrants the modern mammals, and their introduction sounds the death knell of the archaic forms, for one stock after another vanishes and most of them are gone before the close of the Eocene, though the ancient flesh-eaters (creodonts) continue into the Oligocene. Where the modern mammals originated is not yet known, but it appears that there may have been three generating centers for mammals: (1) Africa and southern Asia, (2) Europe and north central Asia, and (3) North America. South America was stocked from North America, but for a long time in the Cenozoic both Africa and South America were isolated and each developed an independent assemblage.

Archaic Mammals. — The North American Paleocene mammals were still archaic, that is, they were very primitive, generalized, omnivorous or fruit-eating, dominantly placental, and small. None of them were as large as a sheep, the limbs were short, with five digits each, the tails were long and heavy, and the brains extremely small. They were closely related to one another and appear to have been the direct descendants of the Mesozoic mammals continued with some change into the Cenozoic. Of orders having living forms, there were present in the latest Mesozoic egg-layers and marsupials, besides insectivores, lemurs, carnivores, rodents, edentates, and hoofed placentals.

It appears that there was free intermigration of the archaic mammals between North and South America toward the close of the Mesozoic and into earliest Cenozoic time. Then all migrations ceased until the middle of the Pliocene, so that during most of Cenozoic time South America was an independent generating center of mammals.

Lower Eocene Mammals. — The most striking feature of the life of early Eocene time (Wasatch-Wind River) was the appearance in considerable numbers, both in western Europe and in North America, of the first representatives of the progressive or modernized mammals. Where they came from is unknown, but it is established that there was free migration between North America, Europe, and Asia during early Eocene time, though there was no further interchange until the Oligocene.

Among these Lower Eocene mammals were diminutive horse-like forms (*Eohippus*), fleetfooted rhinoceroses, tapirs without a proboscis, the first ruminants and pig-like forms, squirrel-like rodents, insectivores reminding one of the European hedgehogs, carnivores, lemurs, monkeys, and probably also marsupial opossums. It was in the main the mammalian life of a mountainous country, superior in foot and tooth structure to the indigenous archaic fauna, and of a higher intelligence. In the struggle for existence the archaic mammals were the losers (58 per cent present in the Wasatch) and before the close of the Lower Eocene their number was far less (Wind River, 37 per cent).

Middle and Upper Eocene Mammals. — In the great abundance of mammals in the later Eocene there was no evidence of new migrants having come from Asia or Europe, but the fauna was dominantly that of the older Eocene with a small proportion of archaic forms (Bridger, 20 per cent; Uinta, 13 per cent), continued with persistent and divergent evolution. The changes were largely toward greater size, more muscular power, and the origination of new indigenous forms. There were many hoofed animals and all were browsers. This was again an upland or mountainous mammal assemblage, on the whole well balanced, with an equal distribution of arboreal, running, aquatic, burrowing, carnivorous, and herbivorous types.

During the later Eocene appeared tiny camels, true tapirs, oreodonts (an extinct group of ruminating hogs peculiar to America, Fig., p. 621), giant pigs or entelodonts (Fig., p. 620), armadillo-like animals with leathery shields, and primitive dog-like forms. In addition there were many hoofed forms, as titanotheres (Fig., p. 634) and the very characteristic gigantic uintatheres (Fig., p. 633) — mammals unlike anything now living — and fleet-footed rhinoceroses. The archaic flesh-eating creodonts were still present (Fig. 211, p. 620). Marsupials were represented by the opossums, and the lemurs and monkeys were still common, though they shortly afterward became extinct in North America.

Oligocene Mammals. — It was during the Oligocene that mammals for the first time took on a modern aspect, for here nearly all were progressive forms. We now begin to get representatives also of still existing families, and of such there were six of rodents, four of carnivores, and one of odd-toed hoofed mammals. Then in this period we get our first knowledge of the varied mammalian life of the open plains and of grazing mammals, indicating that the grasses were taking possession of the open country.

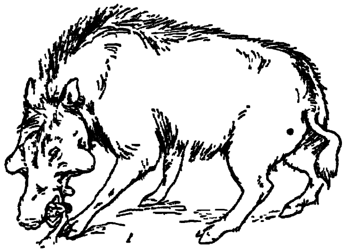

Fig. 210. — One of the giant pigs or entelodonts (*Archæotherium*) of the Oligocene (White River). From Scott's *History of Land Mammals.*

Early in the Oligocene took place a second and more marked invasion from Europe. The interchange was considerable, yet it was not complete and the time of migration was of short duration. Europe lost its horses early in the Oligocene, but in North America there was continued evolution of the three-toed forms. The camels were also better represented (Fig., p. 631), and among them were grazers, these and other hoofed mammals being present in bewildering variety. The tapirs were not common, but of rhinoceroses there were many, some fleet of foot, some stocky, heavy, and amphibious in habit, and of the true rhinoceroses there were forms with and without horns. Rodents were also common, such as beavers, squirrels, pocket gophers, mice, and hares. Among the ruminants, peccaries were numerous, the entelodonts were of large size (Fig., above), and the oreodonts, not unlike the peccaries and wild boars in appearance and size, were exceedingly abundant, varied, and ran in great herds (Fig., p. 621). Among the carnivores, small dogs were remarkably abundant and diversified, in fact, more so than ever before or since. The last of the archaic creodonts occurred here, and as they vanished their place was taken by dogs and later by wolves and the first sabre-tooth cats; true cats, however, were not yet present.

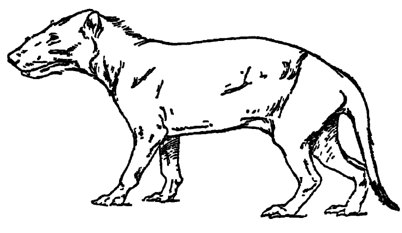

Fig. 211. — Restoration of the last of the creodonts (*Hyænodon*), of Oligocene age. These animals were the direct ancestors of all later carnivores. From Osborn's *Age of Mammals.*

Miocene Mammals. — The Miocene was the "Mammalian Golden Age," and the epoch is replete with interest because of the

changes wrought in the faunas and in the floras by the alteration in climate to cooler and semiarid conditions. Great chains of mountains were being elevated, Eris was being torn apart (see p. 609), and these derangements in the topography and geography had their effects not only on the climate and life, but on the migrations of the mammals as well. The Miocene, and especially the later Mio-

Fig. 212. — A remarkable group of three Miocene oreodonts (*Promerycochœrus carrikeri*). Above are the skeletons as found in the rocks (note how they are huddled together, having met death in this attitude), and below, the animals restored in the flesh. Found by O. A. Peterson in Sioux County, Nebraska. Originals in the Carnegie Museum, Pittsburgh, Pennsylvania.

cene, was therefore characterized by an increase of grassy plains, though this statement is not based on the presence of fossil grasses but is deduced from the change that took place during this period in the mammalian teeth from those of the browsing type to the grinding or grazing kinds (Fig., p. 625). There were now large numbers of horses, camels, ruminants, and rodents with high-crowned, per-

sistently growing, grinding teeth. On account of the silica which the grasses contain, they are very abrasive and rapidly wear the teeth down.

The third marked migration of mammals into North America took place not only during the Miocene but during the Pliocene as well, and the migrants came from Asia by way of the Siberia-Alaska bridge. The most conspicuous among Miocene forms were the four-tusked, browsing, long-faced mastodons, the short-legged rhinoceroses, the cats, and the beavers.

Prominent among the Miocene mammals were the horses, which roamed the plains in great herds. All were three-toed and at first all were still browsers, but in the later Miocene the grazing type predominated. Camels were also plentiful. Rhinoceroses were present in great variety, some hornless, others with a single horn on the end of the nose, and still others with an additional horn on the forehead. The commonest type were extremely heavy, with very short legs (*Teleoceras*); others were long in the legs and less massive in body. Peccaries abounded, and the last of the giant pigs, the entelodonts, occur in the Lower Miocene, one of them being over 6 feet tall (*Dinohyus*). The oreodonts were still very common but vanished with the Middle Pliocene. The first of the true deer appeared in the Lower Miocene and in addition there were hornless deer and antlered deer-antelopes that were slender and graceful little creatures.

Among the carnivores, the dog kinds were in great variety, some small, others as large as the largest bears. True cats appeared here for the first time, and the sabre-tooth tigers were plentiful though not large. There were also weasels, martens, otters, and racoons, but no true bears are known in America before the Pleistocene.

Pliocene and Pleistocene Mammals. — Of Pliocene mammals in America not much can be said, because strata of this age are scarce. The continent stood high and was undergoing elevation in the western portion, with the result that the rivers carried into the sea their loads of sand and mud.

Of mastodons there were several species; the horses, in considerable variety, were still three-toed; llamas and the tallest of giraffe-like camels continued to live; rhinoceroses with and without horns were present; sabre-tooth tigers and true cats existed, some of them as large as the lion.

It is also interesting to note here that in Asia during the Pliocene arose the still living bovine family, the cattle, sheep, and goats.

Earlier in this chapter it was said that migration between North and South America had taken place very early in the Cenozoic, and that the latter continent then for a long time evolved mammals peculiar to it. Probably the most striking of these were the edentates, mammals like the tree sloths, ant-eaters, and armadillos still living in the forests of South America. In the ant-eaters there are no teeth at all and it was this feature that led Cuvier to give them the name edentates, meaning *without teeth;* unfortunately, however, most of the rest of the group have teeth, though not well developed, but peg-like and devoid of enamel. The tail is thick and heavy, suggestive of those in reptiles. Edentates are all sluggish animals.

The most striking of the South American edentates were the huge Pleistocene ground sloths and the highly armored glyptodonts related to the armadillos (Fig., p. 665) and looking like great land tortoises. Both of these animals migrated into the southern United States and are found there in Pleistocene strata.

Of North American mammals, there radiated over the same land bridge into South America in Pliocene time large sabre-tooth tigers (*Smilodon*), large cats, dogs, racoons, horses, llamas, deer, mastodons, tapirs, peccaries, etc.

Euro-asiatic connection with North America is again indicated by the migration of American camels into China and India during the Pliocene. At the same time the hollow- and twisted-horned antelopes came into America, and apparently also an ape (*Hesperopithecus*), along with the short-faced bears (arctotheres) now known in Oregon, Mexico, and South America. The true bears arrived from Asia during the Pleistocene.

In late Pliocene time the mammals attained their climax of development, and this continued into the Pleistocene. Here was also the time of their greatest wandering, since the proboscidians, horses, and camels were world-wide in their distribution. Then came the Ice Age and the ascendancy of man, and one after another the magnificent mammals vanished. To get a picture of this climacteric late Pliocene mammal assemblage we must go to the tablelands of Africa, but here too it is doomed soon to disappear through the advent of man.

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CHAPTER XLIII

THE EVOLUTION OF HORSES AND OTHER HOOFED MAMMALS

The Horses

In demonstrating the truth of evolution, the horses, above all organisms, are the best illustration of the working out of this doctrine by means of natural selection and adaptation to environment. They are the " show animals " of evolution, since their history running back through millions of years is now well known. In this way the famous Yale University Collection, assembled by Professor Marsh, did much to establish the truth of Darwinism (study Fig., p. 627).

Huxley many years ago said that the horse must have been derived from some quadruped which possessed five complete fingers or toes (called digits) on each foot and which had the bones of the forearm and of the leg complete and separate. Moreover, that if the horse has thus been evolved, and the remains of the different stages of its evolution have been preserved, they ought to present us with a series of forms in which the number of digits becomes gradually reduced, the bones of the forearm and leg take on the equine condition, and the form and arrangement of the teeth successively approximate to those which obtain in existing horses. Since Huxley's time, nearly all of the missing links in the evolution of the horses have been found and nowhere is this history so complete as in the Cenozoic formations of the Great Plains of the United States.

The horse is the most useful and beautiful of man's domesticated animals, and has been one of the greatest factors in his civilization. In the early history of man he fed on the horse, and at Solutré, in the department of Saône-et-Loire, France, there is one pile of horse bones estimated to represent 80,000 individuals. Later the horse became man's chief means of travel and his beast of burden in agriculture and warfare. The horse is also among the most perfect and swiftest of organic running machines, as man loves to demonstrate in the race horse. As migrants into all continents, and in adapting themselves to varied environments — from torrid to arctic climes — horses have had but two equals — elephants and man. In

their wild state, horses are now restricted to the open arid plains of central Asia and Africa, since the mustangs and broncos of North and South America are descended from domesticated horses run wild since the days of the Spanish explorers.

Distinguishing Characters. — The horse family (Equidæ, from *Equus caballus*, the living horse) includes the living horses, zebras, and asses. They belong to the odd-toed hoofed mammals (Perissodactyla), in which the axis of the foot lies in the third digit. Horses are characterized by their very long and slender feet, each composed of but a single functional toe, the third digit. The hoof is the equivalent of the nail or claw of the third finger or toe in other animals. Horses therefore walk upon the very tip of the toe, in fact, on the third finger nail, the wrist being what horsemen call the " knee "

Fig. 213. — Upper row, teeth of the browsing "dawn horse," *Eohippus*, of the Lower Eocene: short-crowned, no cement, premolars simpler and smaller than molars. After W. D. Matthew. Lower row, upper teeth of the grazing *Equus* of the Pleistocene: very long-crowned, heavily cemented. Both nat. size.

and the heel the " hock." As the third toe in each limb supports the entire horse, it is necessarily much larger than in animals in which the weight is distributed among several digits. There is, however, on each side of the functional digit, i.e. the " cannon-bone," a slender bone known as the " splint bone." These are the vestiges of the second and fourth toes of the original five in the ancestors of horses (Fig., p. 627). Curious as it may seem, domestic horses are sometimes born with two or three supernumerary toes on one or more feet, and such a one Cæsar is said to have ridden in battle. The whole structure of the horse is preëminently adapted to swift running, and every part of the skeleton has been modified and specialized to that end.

The teeth of horses are as peculiar to them as are their one-toed feet (Fig., above). The molars are long, square prisms which grow

up from the gums as fast as they wear off on the crowns. This wear is accelerated because of the silica in the grasses eaten, and by the sand of the ground that is taken in while feeding. The grinding surface exhibits a peculiar and complicated pattern of edges of hard enamel, between which are softer spaces composed of dentine and of a material called cement, much like dentine in quality but softer and formed in a different way. The dentine is formed on the inside surfaces of the enamel while the tooth is still within the jawbone; the cement is deposited on the outside surfaces of the enamel

Fig. 214. — The "dawn horse" (*Eohippus*) of the Lower Eocene. Restored from a skeleton in the American Museum of Natural History. From Scott's *History of Land Mammals.*

after the tooth has broken through the jawbone and before it appears above the gum.

Evolution. — The horse family has been traced back to near the beginning of the Cenozoic without a single important break. When the little four-toed "dawn horses" (*Eohippus*), no larger than a small dog, appeared in western North America early in the Eocene (Wasatch), the land stood far nearer sea-level than it does now and the climate, though at first with winters, soon became warm and equable throughout the year. Then for a long time the seasons were very much alike and the climate tropical and moist enough

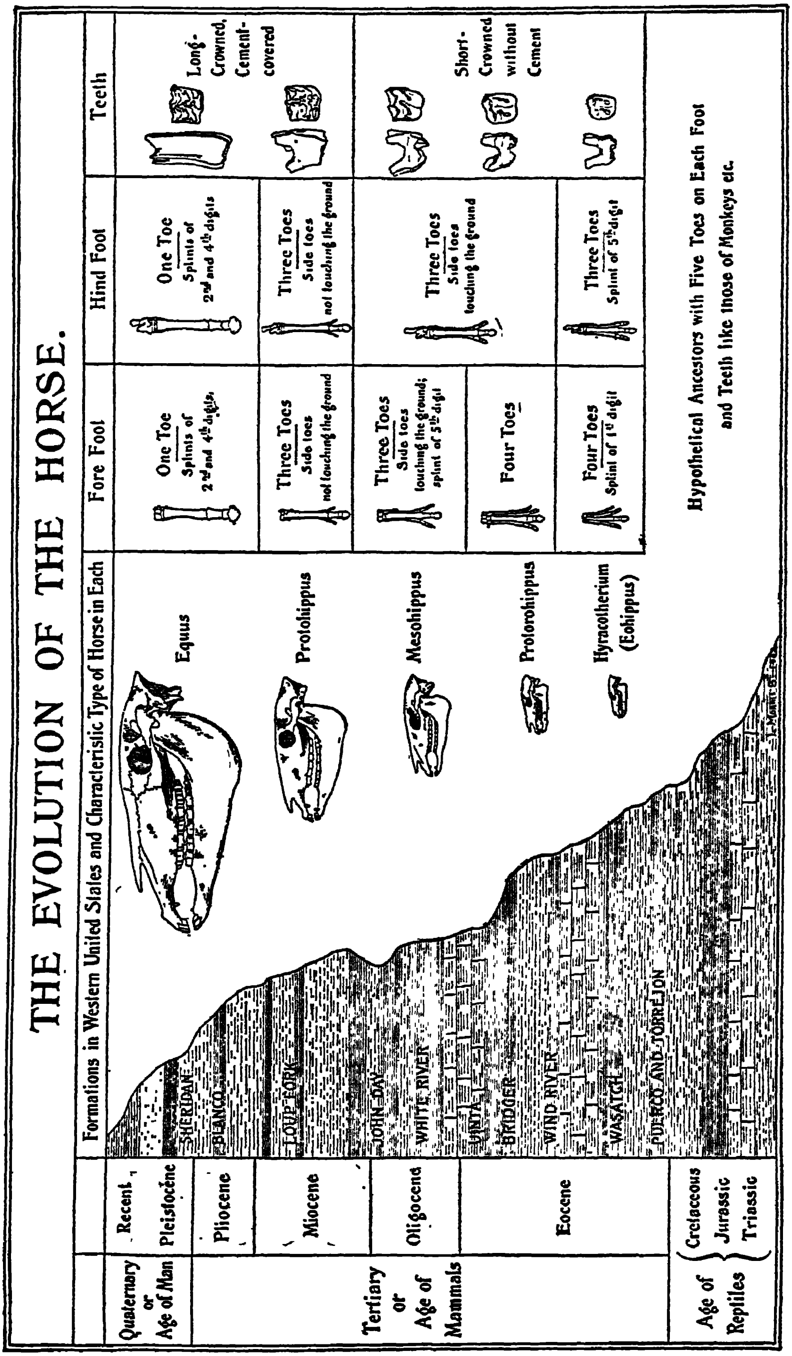

Fig. 215. — Diagram showing the evolution of the horse. After Osborn.

to induce extensive areas of forests, at least over the Cordilleras (Laramide mountains). Over the Great Plains, however, the climate was drier and here were great grassy open plains. With the Miocene the whole of western North America began to rise, attaining culmination of elevation in the Pleistocene. Along with these topographic changes the climate became cooler, drier, and eventually icy cold. To all of these changes in the environment the horses adapted themselves or migrated into more favorable habitats, and in so doing changed from the smaller many-toed forms to the larger, fewer-toed, swifter, and more intelligent ones.

At first the many-toed horses browsed in the forests where they were an easy prey to the carnivores of the time, but with the diminishing of the forests and the appearance of the drier grassy plains, they spread for protection into the open plains, and here they developed more and more speed. With the elongation of the lower part of the limbs and the development of the sprinting habit of getting quickly up on their toes, came the gradual loss, through disuse, of the additional toes, and an equally remarkable change in teeth from a short-crowned browsing to a long-crowned (grazing) type. In this way the horses became one of the most highly specialized of animals adapted to a particular environment.

Where the horse family first originated is not known. The "dawn horses" appear at about the same time, and in the same state of evolution, in western Europe and North America. In Europe they soon died out (Eocene) but North America throughout the Cenozoic was their generating center. Curiously, however, even though horses were present throughout the Pleistocene in both North and South America, they had all died out at some time before the advent of the red men. Our present wild horses are feral, that is, had domesticated ancestors, and those of Asia, Africa and Europe are the descendants of early Miocene horses that spread from North America to Siberia by way of Alaska. Late in the Miocene the North American horses spread into South America.

Matthew recognizes twelve stages in the evolution of the horse family, found in as many different and successive geologic formations. Besides the main line of descent which led into the modern horses, asses, and zebras, there were several collateral branches which have left no descendants.

Scott summarizes the long and marvelous development of the horse family as follows: (1) In size there was a somewhat fluctuating increase, leading by slow gradations from the diminutive horses of the Lower Eocene, about the size of a fox-terrier, to the great

animals of the Pleistocene, about 14 hands tall. (2) The molar teeth, originally low, cusped, and with roots, gradually changed from the browsing type to the very long, prismatic, complex, grazing teeth, and the lower jaws grew in depth to accommodate this elongation. (3) The face grew relatively longer and the eyes were progressively shifted farther back. (4) The short neck was greatly elongated and the individual vertebræ modified so as to give flexibility with no loss of strength. (5) The limbs grew relatively much longer, the bones of the fore-arm and lower leg were fused together, the one on the inner side (radius and tibia) enlarging to carry the entire weight, and the external one (ulna and fibula) becoming more or less atrophied. (6) The feet were much elongated and the median or third digit of each gradually enlarged until it carried the whole weight, at the same time modifying the shape of the hoof so as to fit it to be the sole support of the body. The other toes gradually dwindled and became functionless, though often retained as splints. The first digit was first lost, then the fifth, then the second and fourth were reduced to dew-claws and finally to splints. Thus the pentadactyl horses of the Lower Eocene were transformed into the monodactyl species of the Pliocene and Pleistocene.

Brain and Mentality. — The brain of living horses is large and richly convoluted, implying a high intelligence, but it is not equal to that of the elephant. The docility of the horse and its ability to learn are notable. On the other hand, it is emotional, and its psychology is largely linked up with its normal mode of defense — flight — since the first impulse of a domestic horse on seeing any incomprehensible thing is to run away. In the wild state this same impulse is of the greatest possible aid as a means of survival. (Lull.)

Ancestor of Horses. — When the great English paleontologist, Richard Owen, described the little five-toed "dawn horse" of Europe (*Hyracotherium*) a type closely allied to the American "dawn horse" (*Eohippus*), he did not at all know that he had the ancestral stock of the horses, so unlike was it to the modern form. With the subsequent finding in North America of stages of development between it and other horses, it became plain that *Hyracotherium* was a generalized form descended from a stock that gave rise not only to horses but also to tapirs and rhinoceroses. In this is seen how an ancestral stock deploying into different environments leads eventually into animals looking very unlike one another and yet having within their bodies structures which show their relationships. "The conclusion is unavoidable that horse, rhinoceros and tapir, three races

widely different to-day, are derived through progressive changes from a common ancestral type" (Matthew).

Geologic Succession. — The most ancient known member of the family Equidæ was the "dawn horse," which swarmed in the forests and glades of the Lower Eocene (Wasatch). They were graceful little creatures no larger than a dog, or about 11 inches tall at the withers. They had on the front feet four functional digits and the vestige of another, while the hind feet had three toes and two tiny splints, the vestiges of the first and fifth digits. This evidence clearly indicates that *Eohippus* originated in ancestors with pentadactyl feet. The molars were cusped and short and of the browsing type; the neck was very short,

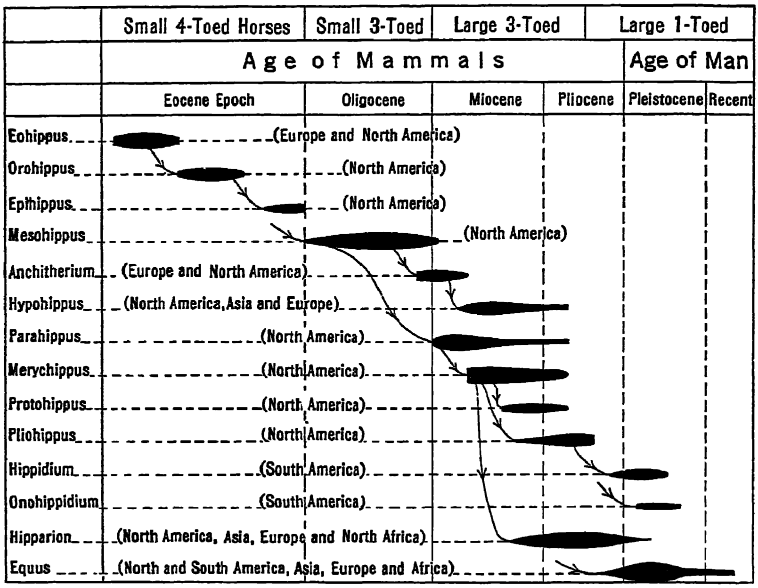

Fig. 216. — Chart showing geologic and geographic ranges of the ancestors of living horses. The thick black lines show the known duration of the genera and the times of their greatest specific abundance. The dotted connecting lines with arrows indicate the genealogy. After W. D. Matthew.

the body long, with an arched back, the limbs and feet short, and the hind limbs much longer than the fore (Fig., p. 626).

The Oligocene horses were intermediate in development between those of the Eocene and Miocene. In the Lower Oligocene (White River) the largest ones were of the size of sheep (*Mesohippus*), and while the teeth were low-crowned and of the browsing type, they were changing toward those of the grazing animal. The front feet had three functional toes, and even though the middle one was the largest, the two lateral digits touched the ground; the hind feet were also three-toed, but there were no splints present (Fig., p. 627).

In the Middle Miocene the three-toed horses were still mostly browsers, though some of the progressive ones were changing rapidly toward grazers. It is here that we get the intermediate forms (*Merychippus*) and note the splitting up of the

horse family into several independently developing phyla. The Lower Pliocene had both progressive and conservative types of these animals. In the Middle Pliocene, among the herds of horses roaming the plains, there were three phyla of three-toed grazing horses, but the lateral digits no longer touched the ground;

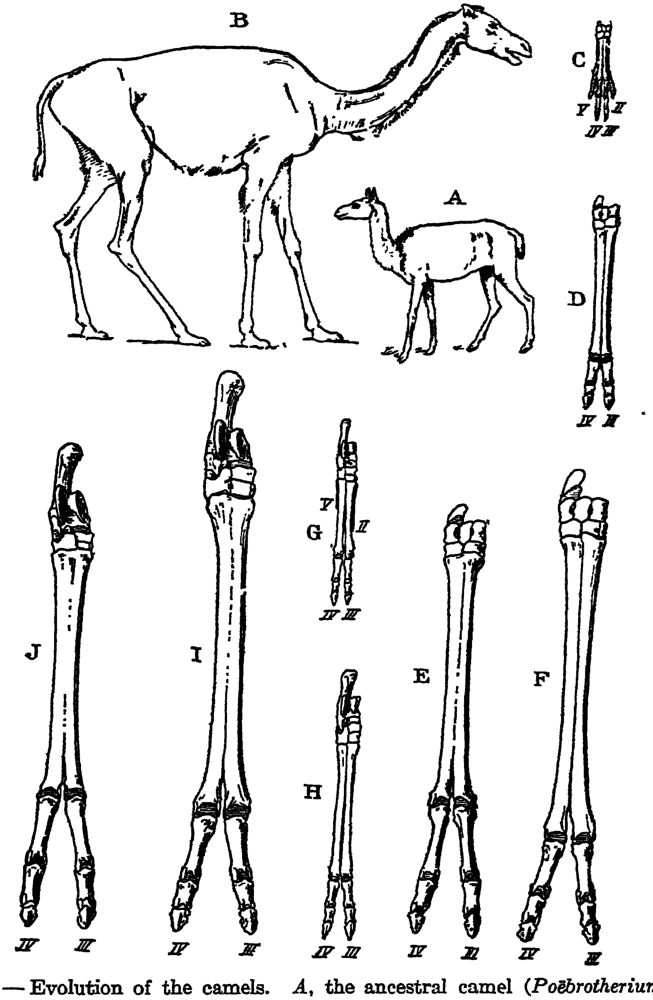

Fig. 217. — Evolution of the camels. *A*, the ancestral camel (*Poëbrotherium*). *B*, primitive giraffe-camel (*Oxydactylus*). *C-F*, right hands of a series of progressively younger camels (*Protylopus* of the Uinta, *Poëbrotherium* of the White River, *Procamelus* of the Miocene, and the living guanaco). *G-J*, right feet of the same series. *B* from Osborn's *Age of Mammals*, the rest from Scott's *History of Land Mammals*.

while they were "dew-claws," however, they were still at times of some supporting value. In the Upper Pliocene occurred the last of the three-toed browsing and grazing horses, and here lived also the first one-toed member of the genus *Equus*. In the earlier half of the Pleistocene there were at least ten species of the same genus, and among them horses larger than any now living. (Study Fig., p. 630.)

The Camels

The family Camelidæ now includes the two species of camels of the desert areas of central Asia and the llamas and guanacos of the higher and colder parts of South America. These strange animals had their origin and essential evolution in western North America and their history runs parallel with that of the horses. They represent adaptations to dry climates and open sandy plains. Camels belong to the even-toed division of hoofed mammals, the Artiodactyla. Here the axis of the foot lies between the third and fourth digits and not, as in the horses, in the third digit.

Camels first appeared in the Upper Eocene in a form about the size of a domestic cat, and then there was a long line of them throughout the Cenozoic. In the Lower Miocene, the camels, like the horses, began to diversify, and large camels were still plentiful in North America during the earlier half of the Pleistocene but soon thereafter became extinct. The llamas spread southward through the tropics into South America in the Pliocene, and at the same time the camel stock radiated northward and finally across the Alaska-Siberia land bridge into Asia and thence into Africa.

Scott states that the mode of evolution shown by the camels differs in no significant regard from that seen in the horses. There was the same increase in bodily stature and in the relative lengths of limbs and feet, a diminution in the number of digits from the original five to two in camels (Fig., p. 631), and to one in horses (Fig., p. 627), and a similar development of the high-crowned grinding teeth from the low-crowned browsing type. The two families of camels and horses each arose in a single series.

The Short-footed Amblypods

Among the archaic mammals of the Eocene there was a stock of browsers, sluggish in habit, clumsy in the mechanics of their skeleton, but abundantly represented by species and genera. These are called Amblypoda, a name which has reference to their short or blunt feet. Their legs were stout and pillar-like, and the short feet had five toes with elastic pads as in elephants. Like all archaic mammals, their brains were small in proportion to the size of their bodies.

Amblypods probably originated in North America during the late Mesozoic, since the oldest forms are known in the Paleocene. They were common in the Wasatch, grew to larger and larger size and became more diversified during the later Eocene, and died out

before the close of this epoch in the Bridger. They are very striking and characteristic mammals in the North American Eocene, and but few of them (*Coryphodon*) migrated into western Europe.

The most striking of the amblypods were the uintatheres, so named from the genus *Uintatherium* (see Fig., below) found in the Uinta Mountains of Utah. Many of the kinds grew to the size of small elephants, 7 feet tall at the shoulders, and in the general shape of their broad legs and feet, but not their heads, resembled the proboscidians. The uintatheres, Scott says, were veritable giants and the most fantastic animals of their time. They were once regarded as proboscidians but it is now established that the two groups are in no way directly related. They were, however, the elephant-like animals of the North American Eocene.

The heads of uintatheres were large, and many-horned, and, curiously, the tops of the skulls were hollowed or basin-like, a feature that is characteristic of them. Of true horns sheathed with horn, as in rhinoceroses, there was a pair over the nose, and over the eyes and ears were other pairs of more or less high bony knobs thought to have been covered only with thick skin. Another striking characteristic, but restricted to the males, was the development of the upper canines into two formidable curved and sabre-like tusks. In order that these tusks should not be broken off in use, the lower jaw developed wide bony flanges for their protection. Their use is unknown. In both sexes the upper set of incisors were suppressed as in many living ruminants. The brain in uintatheres was "absurdly small" and their low mentality among mammals is comparable to that of dinosaurs among reptiles. It may have been the chief cause for their extinction, since they had to compete with the ever rising hordes of larger-brained and therefore more alert modernized mammals.

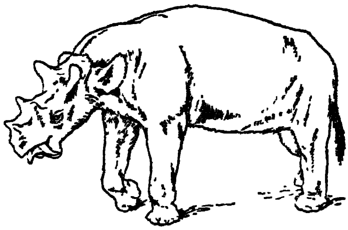

Fig. 218. — Large hoofed uintathere (*Uintatherium alticeps*) of the Eocene (Bridger). From Scott's *History of Land Mammals*.

The Giant-beasts or Titanotheres

In the Lower Eocene, among the immigrant modernized mammals there appeared an odd-toed ungulate (*Eotitanops*), smaller than a sheep and in appearance suggestive of a tapir. This ancestral form, Osborn says, evolved into eleven principal branches, the deployment

beginning in the Bridger, continuing in the higher Uinta, and vanishing at the climax of its development in early Oligocene (White River) time. The most significant evolution of these animals therefore takes place within 200 feet of Oligocene strata. Late in the Eocene they spread into Mongolia (*Protitanotherium*) but apparently did not live long there.

These are the titanotheres, "giant-beasts," which are very characteristic North American Cenozoic mammals. It is only the later forms that attain the size of small elephants, but *Brontotherium*, aside from the elephants, is "the most imposing product of mammalian evolution." Why the titanotheres failed when they were at their best is not known, but it may be that the drier climatic conditions of the Miocene, and the changing of their forest

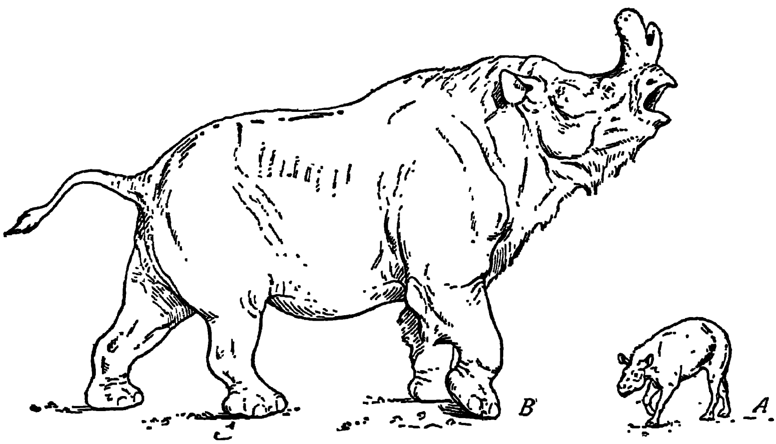

Fig. 219. — Titanotheres. *A*, first stage in the evolution (*Eotitanops* of the Wind River). *B*, last known stage (*Brontotherium* of the White River). After Osborn.

browsing habitats to open grass lands had already begun and if so may have been the cause of their undoing (see Fig., above).

The titanotheres were heavy in body, with columnar legs and short feet, the latter supported on thick pads as in elephants. In all of them the front feet had four toes and the hind three, and in the older and smaller forms the toes and hoofs were more prominent. Their most characteristic single feature lies in the evolution of the head. In the older ones the skull was small, long and narrow, and devoid of knobs. The canine teeth, however, were prominent as tusks and the incisors were used for browsing on the vegetation. Evidently the tusks in the early forms were used as defensive weapons. In the Uinta, Scott says, the titanotheres were larger and had small knobs over the eyes that with time steadily enlarged and

shifted forward, until in the White River these bony horns had attained great size and were situated on the nose. While the horns were enlarging, the skull was being modified to support their weight and to endure better the shock of impact when they were put to use. When the horns had become weapons, the tusks dwarfed into insignificance and the front teeth were no longer used for cropping, this being done by the tongue and upper lip. In the fullness of the titanothere development, the heads were long, very broad, large, and massive; the profile deeply concave, resembling that of some fantastic rhinoceros with nasal horns. In body and limb as well these derived forms resembled large rhinoceroses.

The brain in the largest of the species was very small, no larger than a man's fist, indicating that these great beasts "must have been incredibly dull and stupid, surpassing even the modern rhinoceroses in this respect" (Scott).

The Rhinoceroses

The rhinoceroses belong to the odd-toed hoofed mammals; they are generally three-toed, and typically thick-skinned. As a rule, they have but little hair, although there was a woolly species contemporaneous with man during the Pleistocene in the cold climate of Siberia and northern Europe (*Ceratotherium antiquitatis*). They are browsers and grazers and live in forests, steppes, and marshes. They have large heads, short necks, and very long massive bodies, and their limbs are short, stout, and columnar, like those of elephants. The living forms stand from 4 feet to 6 feet and a half tall at the shoulders, and the single-horned species occur in India and Java, while those with two horns tandem, one on the nose and the other on the forehead, live in Africa and Sumatra. None of the fossil American forms was as tall or as heavy as the largest living form. The horns of rhinoceroses are peculiar in that they are neither hollow as in cattle, nor of bone, but are solid dermal growths made up of agglutinated hairs, and for this reason are never found fossil. Their presence in fossil forms is always indicated, however, by thickened and roughened nasal bones.

Since Middle Pliocene time there have been no rhinoceroses in North America, and yet this continent may have been not only the place of their origin, but that of their most significant evolution as well. The origin and development of the ancestral forms in North America and later of the true rhinoceroses of the Old World is a very complex history, much more so than that of the horses and titanotheres. Rhinoceros-like mammals appeared in America early in the Eocene

in small, active, and generalized forms (*Hyrachyus*, Fig., p. 638) that in the course of the Cenozoic deployed into at least eight branches. These are again grouped into four main lines of evolution, namely, (1) the ancestral stock of small, defenseless and hornless, *running* rhinoceros-like forms; (2) a specialized and large, short-lived, *aquatic* type that lived in rivers and lakes; (3) the gigantic baluchitheres of Asia; and (4) the main stem of *true* slow-moving, huge, usually horned rhinoceroses. In Miocene and Pliocene times, these animals had their widest distribution, living then in all continents except Australia and South America. The ancestral and

Fig. 220. — The small pair-horned rhinoceros (*Diceratherium cooki*) of the Lower Miocene of Nebraska. From Scott's *History of Land Mammals*.

aquatic stocks died out in North America during the Oligocene, and all of them early in the Pliocene.

Hornless forms arose first, and later on at different times in the Cenozoic appeared horned ones. The horns may be single, or double in a transverse pair (=pair-horned), or arranged one behind the other along the median line of the head (= tandem-horned); usually they are placed over the nose, but in some the horn is on the forehead. The presence of horns, as in the titanotheres, led to changes in the shape of the skull (see Figs., above, and p. 637).

The largest land mammal so far discovered was a hornless form of rhinoceros known as *Baluchitherium*. It lived in either late Oligo-

cene or early Miocene time, and was first found in Baluchistan, but has since been collected in Turkestan and Mongolia. Osborn says it stood about 13 feet tall at the shoulders, and was about 25 feet long; in comparison all other rhinos are small. The neck was long and horse-like, the head long and narrow, and about 5 feet long, with two powerful tusks. The limbs were very long and stilted, enabling the animals to browse on the foliage of trees.

Of *true rhinoceroses* Scott says there are seven branches, three of which have living representatives. It appears that these striking animals had their origin in the North American genus *Trigonias* of the lower White River, a hornless

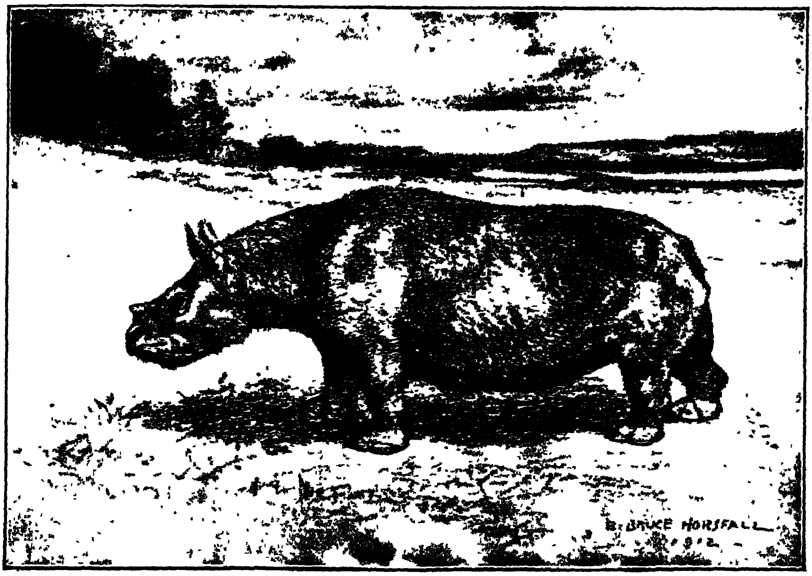

Fig. 221. — The short-legged aquatic rhinoceros (*Teleoceras fossiger*) of the Upper Miocene and Lower Pliocene of Nebraska. From Scott's *History of Land Mammals.*

form with four toes on the front feet instead of three as in all other rhinoceroses. Another hornless rhinoceros of the same time was *Cœnopus*, tridactyl on all feet, and this type persisted into the Pliocene. Conspicuous among the horned rhinoceroses were the small diceratheres (pair-horned), beginning in the Oligocene and persisting into the Miocene (Fig., p. 636). They also migrated into Eurasia, and are characterized by a transverse pair of horns on the nose. Finally from the Old World there came to North America, in the Middle Miocene, *Teleoceras*, an aquatic type with a small horn on the nose, and grotesquely short legs, so that the belly almost touched the ground (Fig., above). This stock persisted in great numbers into the lower Pliocene.

In the Upper Miocene and Lower Pliocene of this continent there were at least four distinct types of rhinoceroses living in great

abundance, but none of them attained the size or bore the great horns of living species. Why they failed to live later, and why the woolly rhinoceros of Eurasia did not come to North America along with the mammoth is not known.

The hyracodonts are the ancestral hornless animals out of which all rhinoceroses came. The oldest one occurs in the Eocene (Bridger) and all of them died out in the Oligocene (White River). *Hyrachyus* (Fig., below), the oldest genus, is much generalized, and out of it might have also developed the horses and titanotheres. It was about as large as a sheep, but heavier. Hyracodonts were lightly built, with heavy clumsy heads, but slender and long necks and limbs; they are suggestive of horses rather than rhinoceroses. In fact, the feet of the White River forms resemble those of horses of the same time (*Mesohippus*). For safety they depended upon speed, and accordingly are called cursorial or

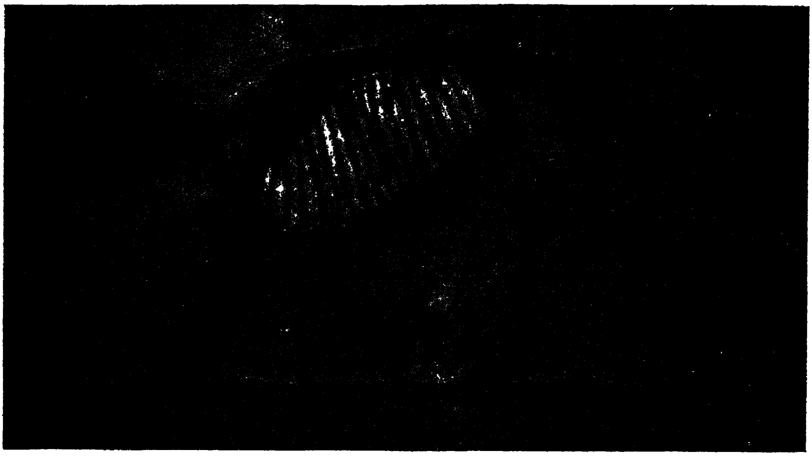

Fig. 222. — Mounted skeleton of an ancestral, hornless, cursorial rhinoceros (*Hyrachyus affinis* var. *gracilis*). Original in the Peabody Museum, Yale University.

running rhinoceroses. Scott says that it is interesting to reflect that had the White River hyracodonts and the ancestral tapirs continued to live up to the present, they would in the course of their evolution have developed one-toed feet as did the horses. In the hyracodonts, as in the horses, the evolution was mainly in the elongation of neck, limbs, and feet, and in the enlargement of the middle toes. With the increase in the size of their bodies in the course of their existence, the limbs became stouter, but all were of the cursorial or running type. In but one genus was a pair of small nasal horns developed (*Colonoceras*).

The amynodonts were the specialized hornless aquatic rhinoceroses. They probably originated in *Hyrachyus* in late Bridger time and died out in the Oligocene. *Amynodon* was smaller and lighter than the later and larger *Metamynodon* of the White River. According to Scott, the latter was the heaviest and most massive creature of its time. Its head was large, depressed, and broad,

the nostrils high on the head in keeping with the aquatic habits, the neck short, the body long and massive, and the limbs short and stout, with four toes on the front feet and three on the hind ones.

Collateral Reading

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CHAPTER XLIV

THE EVOLUTION OF THE ELEPHANTS

Among the animals of the Cenozoic, there was no group more spectacular in its evolution and distribution than the bulky trunk-bearing elephant stock, and among present-day land mammals, they still lead in size, strangeness of form, and bulk of brain. Of living elephants there are, however, but two kinds, the larger, big-eared ones of Africa, some of which attain a weight of about 8 tons and a height of 13 feet at the shoulders, and the somewhat less heavy and smaller-eared type found in India and central Asia.

Elephant-like mammals are technically known as *Proboscidea*, the proboscis being the trunk which is their most characteristic feature. This is in reality the greatly elongated nose, nostrils, and upper lip, forming a very flexible and powerful muscular adjunct to the head, and serving many purposes but used chiefly in gathering food and water and conveying them to the mouth far above the ground. The trunk is also a highly developed sense organ and when held high above the head can detect water and enemies far afield. Sight is far less well developed. As the proboscidian neck is very short and the head very heavy and the legs long and pillar-like, in the evolution of the group the long proboscis had to be developed to enable the upper lip to reach the ground for the purpose of food gathering.

The head of elephants is not only large, but is peculiar also in its great height compared to its width, in other words, it is bulldog-like. The height of the skull is an adaptation to give greater muscular area and therefore stronger leverage for the neck muscles which support the head and trunk. The upper part of the skull is, however, decidedly cellular. The greater transfiguration of the proboscidians took place in the head and in the trunk, beginning in long-headed forms with very short trunks and progressing steadily into the present high type of skull with long trunk.

The brain in elephants is large, about twice the size of that in man, and is primitive in structure in that the fore brain (cerebrum) does not cover the back brain (cerebellum) as in most other mammals.

Elephants are now restricted in the wild state to the forests and jungles of southeastern Asia and central Africa. In the Pleistocene,

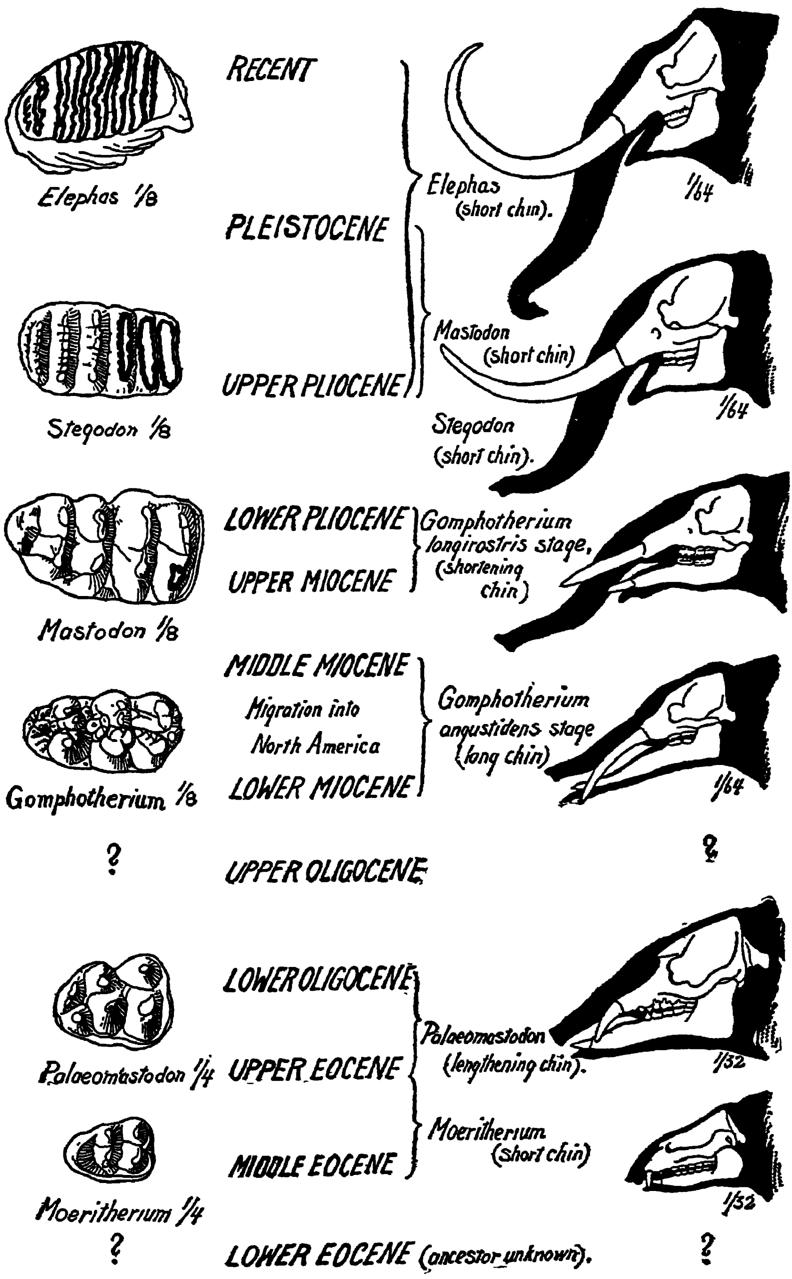

Fig. 223. — Evolution of the Proboscidea. On the right, a series of skulls with the flesh restored in silhouette. On the left, last lower molar. After Lull, from Scott's *History of Land Mammals.*

however, their distribution was nearly world-wide and in all climates, even the very cold ones of Siberia and Alaska north to the Arctic Ocean. The more primitive forms are thought to have been stream and lake dwellers, that is, amphibious in habit, and not until the group took to the forests and grassy plains did their distribution become so general.

The remains of the Pleistocene proboscidians are commonly found near the surface and in peat bogs or marshes. Orange County in southeastern New York has yielded no fewer than thirty-one skeletons. It is usually the teeth or the large limb bones that are recovered and the finding of these in the Dark Ages led to the stories of giant ancient peoples. Or they were thought to be the remains of the "huge earth-shaking beasts" used by the Romans in their invasions of western Europe. It was the great naturalist Cuvier who first successfully demonstrated in the nineteenth century that the bones of elephants found in western and southern Europe were of species wholly unlike those living at present. One of these he called mastodon, which means *nipple-tooth,* in reference to the highly crested or coned nature of the grinding surface of the teeth, which is the common type.

Fig. 224.— Head of the European aquatic proboscidian (*Dinotherium*), with recurved tusks in the lower jaw for digging purposes. × $\frac{1}{36}$. From Osborn's *Age of Mammals*.

Origin. — In 1901, Beadnell and Andrews made known three kinds of proboscidians from the late Eocene and the Oligocene of Egypt (*Mœritherium, Palæomastodon,* and *Phiomia*). The first and last of these have since been discovered also in southern Asia. The origin of the stock is therefore to be sought in the early Eocene of Eurasia or Africa.

Evolution. — Instead of there being but two main stocks of trunk-bearing animals as commonly assumed, Osborn now determines twelve lines of evolving forms.

These group themselves into four main branches, as follows: (1) The mœritheres, found in the Upper Eocene and Lower Oligocene of Egypt; these were small animals, devoid of a trunk, which lived in swamps and may or may not be proboscidians. (2) The specialized dinotheres, amphibious forms, some as large as the greatest mastodons, with no upper tusks but with lower ones that are large, stout, and curved downward as in no other stock of proboscidians, and with a trunk that was undoubtedly large and heavy; they occur in the Miocene and Pliocene of Europe, Asia, and Africa. (See Fig., above.) (3) The mastodons,

A

B

C

D

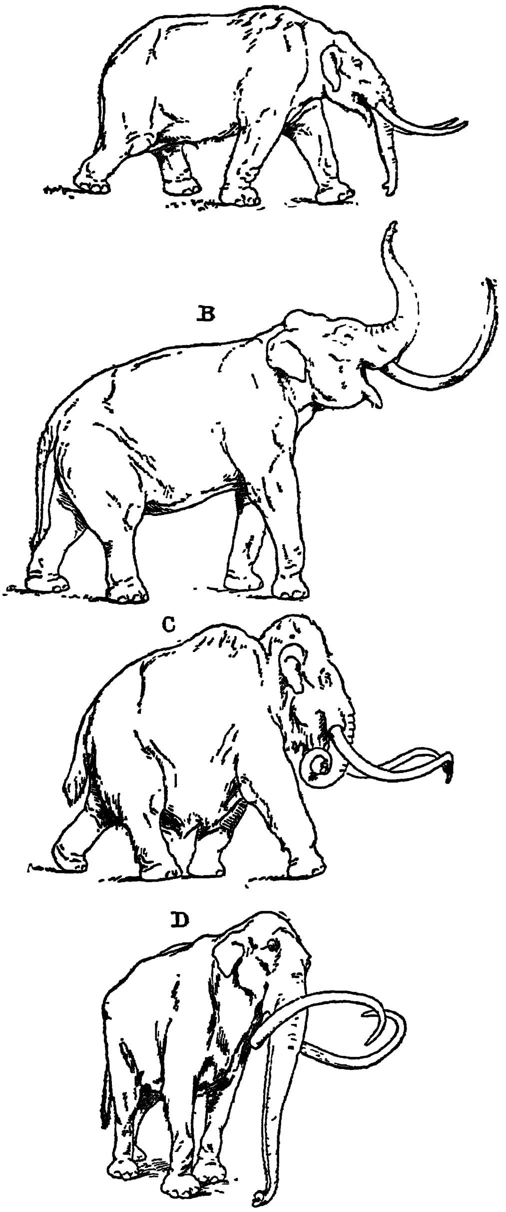

Fig. 225. — Restorations of the American Pleistocene proboscidians. *A*, American mastodon (*Mammut americanum*). *B*, Imperial mammoth (*Elephas imperator*). *C*, woolly mammoth (*E. primigenius*). After Osborn. *D*, Columbian mammoth (*E. columbi*). From Scott's *History of Land Mammals*.

a highly diversified stock, the main line of browsing proboscidians, originating in *Palæomastodon* of the Lower Oligocene of Egypt, of world-wide distribution in the Miocene and especially the Pleistocene, and dying out during the last of the Ice Age. (4) The elephants, or grazing proboscidian stock, originating in the Pliocene, also attaining world-wide dispersal in the Pleistocene, and represented in the living world by the African and Indian elephants.

The oldest known proboscidian-like animal is *Mœritherium* of the Upper Eocene and Lower Oligocene of Egypt. This was about the size of a tapir but without even an incipient trunk. Even though it was at first thought to be the ancestral stock of all the trunk-bearing mammals, it is now not clear what its relationship to the proboscidians is. In any event, it shows how these animals may have evolved. The head was long and narrow and the face rather short, with no suggestion of any trunk. The most interesting feature, however, was the appearance of tusks that originated in the second incisors, the other front teeth remaining small. The incipient upper tusks were quite prominent and directed sharply downward, while those of the lower jaw were nearly procumbent, with a slight upward inclination (Fig., p. 641).

Palæomastodon of the Lower Oligocene of Egypt, the oldest undoubted proboscidian, was much smaller and more generalized. It was about the size of a tapir, the narrow face was more drawn out than that of the older *Mœritherium,* and there was a well-developed, flexible snout rather than a trunk. The tusks of the skull were longer, compressed, and more outwardly directed; those of the jaws, while larger, pointed straight forward. All of the grinding teeth (premolars $\frac{3}{2}$, molars $\frac{3}{3}$) were in place and functioned at the same time, which is not true of the later proboscidians (Fig., p. 641). The limbs were like those of elephants.

The many kinds of mastodons of the Pliocene and Miocene were smaller than those of the Pleistocene. Some were two-tusked (*Dibelodon*) and others were long-faced and had four tusks (*Tetralophodon, Trilophodon, Gomphotherium*). It was out of the long-faced forms that has come the fullness of proboscidian development. In North America the best known form is the American mastodon (*Mammut americanum*), skeletons of which are found from Florida north into Alaska, from Connecticut to California, and from central Russia eastward throughout Siberia.

Of elephants there are at least a dozen extinct species. Matthew says some are nearest in relationship to the living Indian elephant (*Elephas*), others to the African (*Loxodon*), while still others (*Stegodon*) are intermediate between these and the older mastodons. Three

species occurred in the Pleistocene of North America, the hairy mammoth and the Columbian and Imperial elephants, all of which were very large. Of these, the mammoth (*Elephas primigenius*) is best known, and its distribution was very wide, not only in America but in Europe and Asia as well. In Europe its remains occur as far south as Spain and Italy and in America from North Carolina and California northward. The term "mammoth," however, does not mean gigantic in size but comes from the Tartar word *mama'ntee*, meaning *earthmouse*, a habitat assigned these animals by a Chinese legend which says they lived underground and perished when they came into the light of day (see Fig. *C*, p. 643).

Summarizing the evolution of the Proboscidea, according to Lull: Increase in size and the development of pillar-like limbs to support the enormous weight; increase in size and complexity of the teeth and their consequent diminution in numbers and the development of the peculiar method of tooth succession; loss of the canines and of all of the incisor teeth except the second pair in the upper and lower jaws and the development of these as tusks; gradual elongation of the symphysis or union of the lower jaws to strengthen and support the lower tusks while digging, culminating in *Gomphotherium;* the apparently sudden shortening of this symphysis following the loss of the lower tusks and the compensating increase in size and the change in curvature of those of the upper jaw.

The increase in bulk and height, together with the shortening of the neck required by the increasing weight of the head with its great battery of tusks, necessitated the development of a prehensile upper lip which gradually evolved into a proboscis for food-gathering. The elongation of the lower jaw implies a similar lengthening of the proboscis in order that the latter may reach beyond the tusks. The trunk did not, however, reach its greatest usefulness until the shortening jaw, removing the support from beneath, left it pendent as in the living elephant.

Migration. — *Palæomastodon* or its descendants, the long-faced tetrabelodons, crossed from Africa by way of a land bridge through the Mediterranean from Tunis, Sicily, and Italy to Eurasia. This bridge was in existence in Oligocene time. From here the deployment was both to the west into Great Britain and possibly even to North America by way of an early Miocene bridge connecting America and Europe across the Shetland Islands, Iceland, and Greenland, and eastward across Asia and finally by way of Siberia as far as Nome in Alaska. Finally in the Pliocene the elephants spread from North into South America. Hence the proboscidians

have been world-wide travellers, equalled only by the horses, and exceeded only by man.

Elephants Contemporaneous with Man. — In western Europe there is excellent evidence that man was well acquainted with the hairy mammoth, since toward the close of the Pleistocene he engraved its picture on bone and ivory and painted it on the walls of caves. There can be no doubt that man, the hairy mammoth, and other proboscidians were contemporaneous throughout the Pleistocene in Eurasia, and in America it appears that the mound-builders also knew either the elephants or mastodons, since they built mounds resembling them in shape.

Collateral Reading

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CHAPTER XLV

PLEISTOCENE TIME AND THE LAST GLACIAL CLIMATE

The Pleistocene, the final division of the Cenozoic era, and hence of geologic chronology, though brief as compared with the older divisions, was one of the critical times in the history of the earth. It was the time of the "Great Ice Age," and the record of the areas where the ice-fields prevailed consists in the main of a varied and most often a heterogeneous series of continental deposits, all of this being the Diluvium or deluge material of the older philosophers and the drift or tills of modern students of earth science. The bowlder beds of the ancient glacial deposits are known as tillites, while the glacially made banded clays have recently been named pellodites. Outside of the areas of glaciation the strata are in general like other continental formations laid down under moist and warmer climates. The exposed marine record is nearly everywhere very scanty, and the molluscs are almost all (at least 90 per cent) or all still living. The life of the land was also dominantly of living forms, though here the percentage of extinct species was greater than in the seas. The term Pleistocene was therefore proposed by Lyell to bring out the fact that the life of this time was very much like that of the present. In Europe, this time is usually known as the Quaternary.

Cold Climate of the Pleistocene. — The distinguishing physical feature of Pleistocene time was its very extensive glaciation; in fact, there appear to have been a series of glaciations, for ice-sheets covering about 8,000,000 square miles of the earth's surface existed at one time or another during this period in the temperate and colder regions of the two hemispheres (Fig., p. 649). This is all the more remarkable when we consider that the ice-sheets were mainly of the low lands, and that the climates for a very long time previous had been mild. All of the water of these ice-sheets had been taken from the oceans and precipitated as snow on the continents. The decrease of temperature was such that the snow-line (see Pt. I, p. 120) was lowered about 4000 feet below its present limit (Fig., p. 653), and the strand-lines of the oceans in the tropical and warm temperate regions, because of the abstraction of ocean water, were depressed probably

not less than 200 feet and not more than 420 feet. Finally, the loading of the lands with so much ice caused the crust to subside in the areas of the ice-sheets, while the regions immediately outside of the latter were apparently somewhat upwarped in compensation by the displaced deep-seated material of the sinking fields. The surface of the glaciated lands was therefore more or less unsteady, warping up and down some hundreds of feet in consonance with the changes going on in the ice-sheets during Pleistocene time. In addition, broad crustal movements unrelated to the glaciation had been in progress during the Pliocene and continued at intervals in the Pleistocene. As a result of these combinations of several causes the streams and shorelines generally show at the present time the marks of extreme youth — sharp gorges, drowned channels, barrier beaches, and elevated strand-lines.

Critical Life Conditions during the Pleistocene. — The development of such immense ice-fields upon the lands and the attendant reduction of temperature also meant the blotting out of vast areas on which no life or at least but little could exist. The Pleistocene was, therefore, a critical time in the history of the earth, especially for the plant and animal life of the glaciated lands and the shallow-water life of the northern and southern oceans. The cold waters, pouring into the oceans, sank into the depths, and the conditions there also became critical for the sparse life. In the shallow waters of the warm parts of the ocean, however, there was almost no change in the environment, and consequently there is recorded here almost nothing more than the usual evolutional faunal alterations.

Recent Time. — The Pleistocene was followed by the Recent, or present time, but how long this has been going on can not yet be stated. In a general way, we may say that the estimates vary between 20,000 and 50,000 years, with the probability that the smaller figure may be nearer the truth. From a study of the glacial clays of Sweden, which there and elsewhere are laid down in layers, a lighter colored winter layer alternating with a darker and thicker summer one, De Geer concludes that that country became habitable 17,000 years ago. The melting of the glaciers began earlier in Germany, hence the greater estimates given above. As man has dominated the organic world since the beginning of the Recent, this is also known as Psychozoic time, a name given it by LeConte. We are living in the opening events of a new era, the Psychozoic Era, but how long it is to last before another critical closing time appears, who can tell?

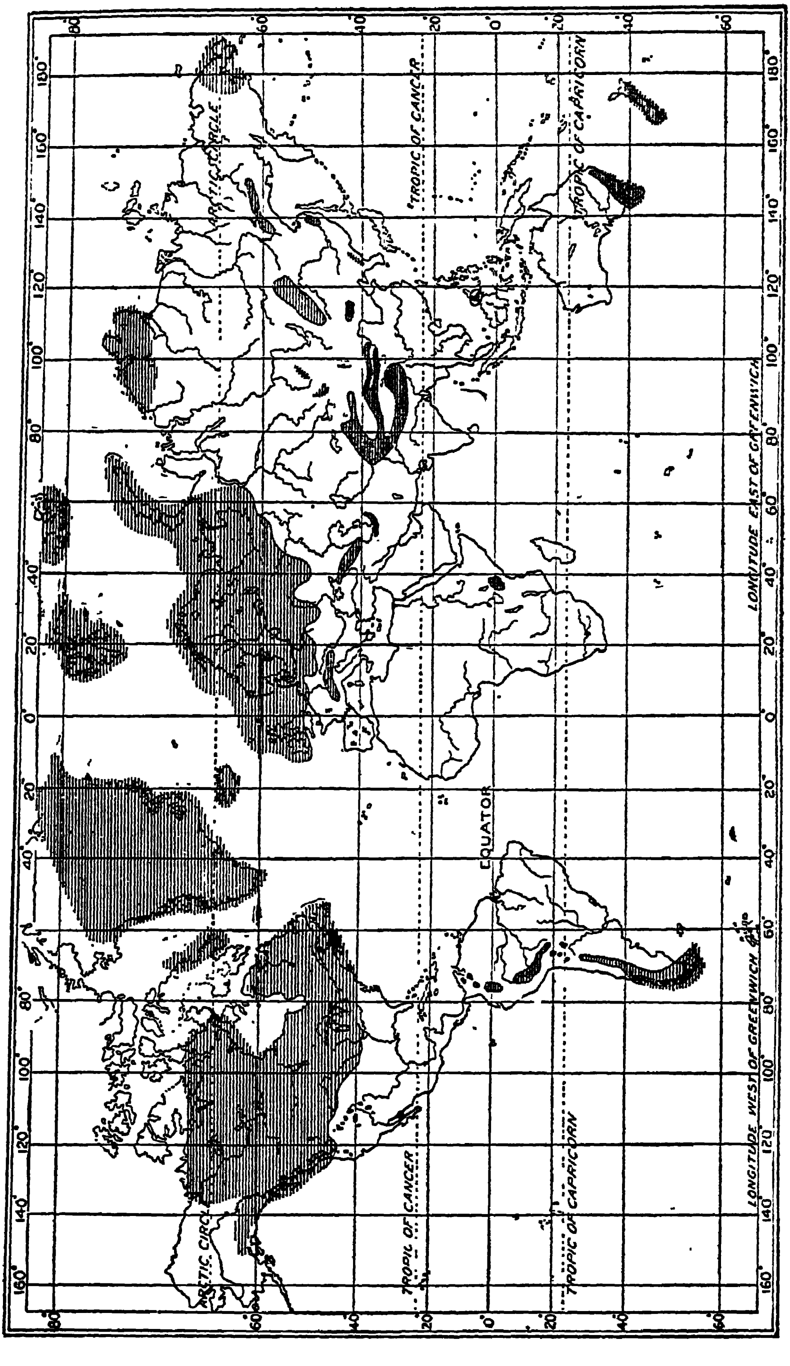

Fig. 226. — World map of Pleistocene glaciation. Carnegie Institution of Washington.

General Distribution of Glaciation

In the discussion of Pleistocene glaciation it should be recognized that the ice has only partly withdrawn. Greenland and Antarctica are still mantled with continental ice-sheets in contrast to their unglaciated state in earlier periods. It is the excess of glaciation beyond the present areas that is to be considered in the discussion of the wide distribution of the ice-fields of the Pleistocene.

More than half of the glaciated area during the Pleistocene was in North America, and more than half of the remainder in Europe. The glaciation was, therefore, notably localized, though its effects were world-wide (Fig., p. 649).

North America. — In North America it was mainly the northeastern half, and the plains country rather than the mountainous region, that was deeply buried under the continental glaciers (Pt. I, p. 124). Alaska was in the main free of ice and the same appears to have been true of the Arctic archipelago. There were three great centers of ice accumulation and radiation in North America, covering together an area of about 4,000,000 square miles (Fig., p. 651). The *Keewatin ice-sheet* was the most extensive, covering the great medial flat area of the continent southward into Missouri and westward into the high plains to within 800 to 1000 miles of the Rocky Mountains. The *Labradorean ice-sheet* was not much smaller, and extended from northern Labrador southwestward for 1600 miles to the Ohio River. The main flow of the ice was southward toward the region of melting, marked by greater warmth. *Newfoundland* and *Nova Scotia* appear to have had independent ice-sheets, while *Greenland* was glaciated more extensively than now but not completely across Davis Strait so as to connect with the Labradorean mass. The *Cordilleran ice-sheet* covered all of the Cordilleran area from Alaska southward into Oregon, Idaho, and Montana. Farther south there were local alpine glaciers in the Rocky Mountains and in the Coast Range and the Sierra Nevadas of California (Fig., p. 651).

Some students of North American glacial deposits hold that the Cordilleran ice-sheet attained maximum spread before the Keewatin one, and the latter before the Labradorean sheet; in other words, that the maximum accumulation of ice shifted more and more to the east during Pleistocene time. In Europe, the accumulation shifted westward with time. On both sides of the North Atlantic, therefore, the shifting of ice accumulation was toward this ocean.

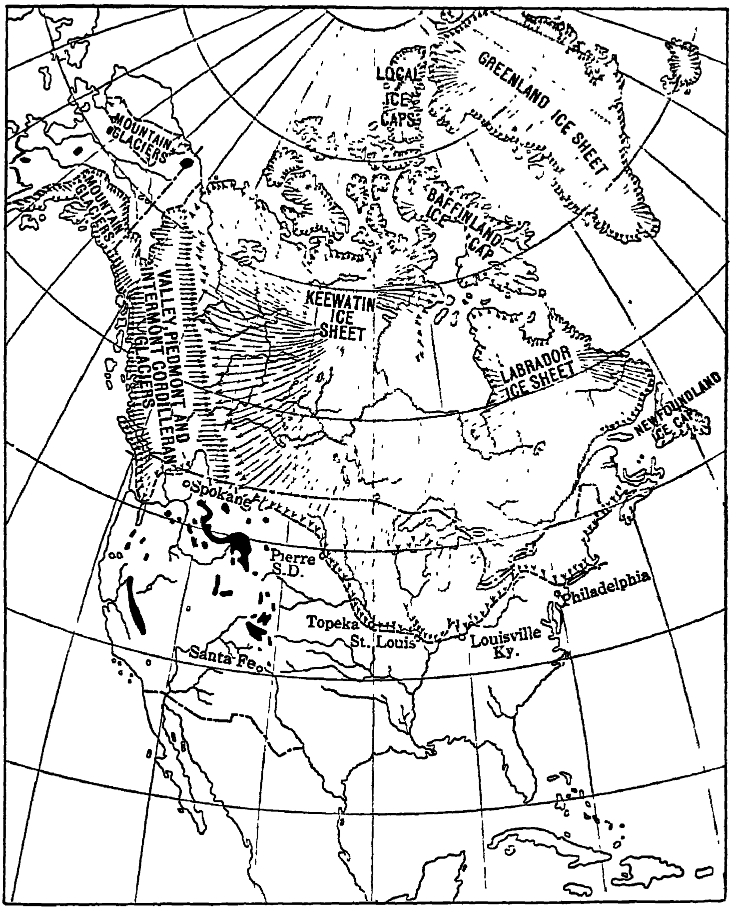

Fig. 227. — Map of maximum glaciation of North America. The white spot in Wisconsin is the "driftless area," a region never covered by glaciers. The solid black reas are mountains covered by local glaciers. After L. Martin, 1916.

Other Countries. — All *northwestern Europe, Iceland,* and *Spitzbergen* were deeply buried under ice-sheets, and the glaciers of the Alps descended far beyond their present limits and coalesced on the low lands in all directions. In the Himalayan region and locally in eastern Asia there were other mountains which were broadly glaciated. In the southern hemisphere, doubtless because of the absence of broad lands in high latitudes, there was comparatively little glaciation, most of it being restricted to the Andean areas. *Antarctica* is assumed to have been as deeply covered with ice then as it is now. (See Fig., p. 649.)

Thickness of the Ice-sheets. — How thick the Keewatin and Labradorean ice-sheets were is not known. It is widely held, however, that they must have been some thousands of feet in depth to have enabled them to flow southward with a descending grade across the higher irregularities. LeConte places the thickness at 10,000 feet over Canada and 6000 feet over New England. Daly (1915) places the least thickness at 1950 feet and says it may have been three times as great. Geologists as a rule believe that the thickness at the centers of ice dispersion could not have been less than 4000 feet, and that it may have exceeded this average depth.

Alternating Cold and Warm Stages

It is a well-known fact that in most areas of past glaciation there occur, between sheets of drift, beds of peat and clays with fossil leaves and wood, and sands with bones of many kinds of large mammals. These fossils show clearly alternating groups of plants and animals living in different climates; one set is of northern origin and of cold habitat, while the following one is from the south and of mild climes. The cold climate assemblages have among other forms reindeer, caribou, musk-oxen, moose, woolly mammoths (Fig. C, p. 643), and walrus, while those of the warm climates have lions, sabre-tooth tigers, peccaries, tapirs, camels, llamas, many horses, hippopotamuses, great sloths (Fig., p. 665), the Columbian and Imperial elephants (Figs. *B, D,* p. 643), and the manatee or sea-cows. It is the succession of these fossils in the Pleistocene strata that has led to the discerning of alternating warm and cold climates. These marked alterations led to very extensive migrations of mammals from one part of the continent to another, as the conditions of temperature and moisture changed. During the warm interglacial times, southern species spread far to the north, as when mastodon ranged into Alaska (Fig. *A*, p. 643) and the sea-cow spread north to New Jersey. Increasing cold and the spread of glaciation brought about a reverse migration and drove northern and even Arctic forms far to the south. Musk-oxen then spread into Utah and as far south as Oklahoma,

Arkansas, Missouri, Ohio, and Pennsylvania; the northern or hairy mammoth (Fig. *C*, p. 643) lived south of the Ohio and Potomac rivers, and the walrus had its home along the strands of New Jersey.

It has come to be generally held, therefore, that during the Pleistocene the temperature varied more than once between cold and warmer climates. During the cold times there was increase in the extent and thickness of the continental ice-sheets, and during the warmer interglacial stages the ice was melted away to a greater or less degree. However, as to the number of these alternations there is as yet no unanimity among geologists, because of the great difficulties in correlating the separated areas of glacial material, all of which are so much alike. Some geologists recognize three, and others as many as six glacial stages, with from two to five interglacial warmer times

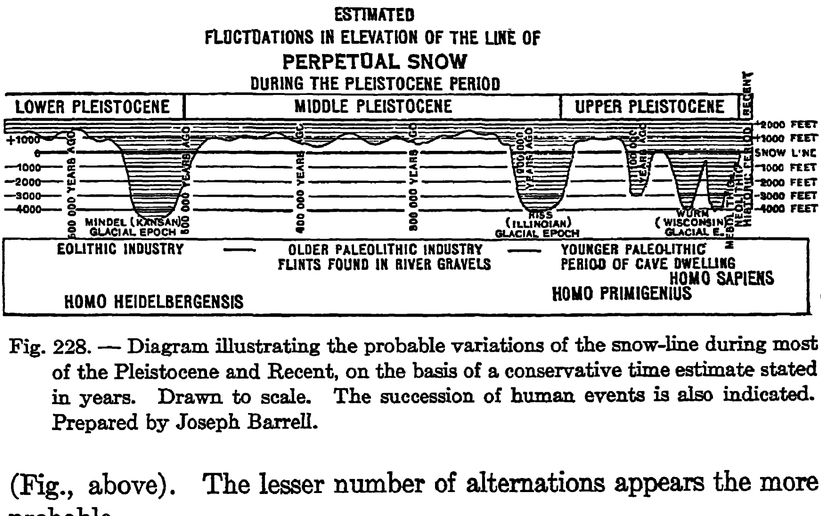

Fig. 228. — Diagram illustrating the probable variations of the snow-line during most of the Pleistocene and Recent, on the basis of a conservative time estimate stated in years. Drawn to scale. The succession of human events is also indicated. Prepared by Joseph Barrell.

(Fig., above). The lesser number of alternations appears the more probable.

It is also now widely accepted that the interglacial times were markedly variable in duration and that all of them were not only warmer than the present, but that they lasted longer, and sometimes much longer, than the glacial stages. In Europe one of the interglacial times was so warm that the lion and the hippopotamus lived with man in England, and in North America the pawpaw bush spread north at least as far as Toronto, while to-day it is not known to live much above the Ohio River.

Chamberlin and Salisbury divide Pleistocene time as in the first column of the following table, and the statements concerning the mammals in the second column are after O. P. Hay. The time estimates in the third and fourth columns are by T. C. Chamberlin (1919).

After Chamberlin and Salisbury	After O. P. Hay	Maximum Years	Minimum Years
Post-glacial or present time	Vanishing of ice-sheets. Champlain marine invasion. Lowering of water-level of Great Lakes. Gradual amelioration of climate. Gradual extinction of elephants, mastodons, *Megalonyx*, musk-oxen, etc.	25,000	20,000
	Divisions of Pleistocene time in North America		
Fifth or Wisconsin glacial stage Würm stage in Europe	Spread of ice-sheets and drift. Fauna and flora driven south.	40,000-95,000	30,000-60,000
Fourth or Peorian interglacial stage	Record not well determined. Formation of peat beds and soils. Wide distribution of loess.	135,000	90,000
Fourth or Iowan glacial stage	Spread of ice-sheets and drift. Record not well determined.	180,000	105,000
Third or Sangamon interglacial stage	Accumulation of peats, soils, and loess. Horses, elephants, mastodons, bison, peccaries, and tapirs probably present.	260,000	155,000
Third or Illinoian glacial stage Riss stage in Europe	Spread of ice-sheets and drift. Deposition of loess. Apparently 60 per cent of present land fauna then living. Mastodons, mammoths, horses, tapirs, bison, deer, and sabre-tooth tigers.	340,000	190,000
Second or Yarmouth interglacial stage	Formation of peats, soils, and bluish loess. Animals about as in Illinoian stage.	500,000	275,000
Second or Kansan glacial stage Mindel stage in Europe	Spread of ice-sheets and drift. Extinction of certain camels and horses, *Megatherium*, *Glyptodon*, and *Elephas imperator*.	660,000	330,000
First or Aftonian interglacial stage	Great abundance of mylodons, megatheres, *Megalonyx*, mastodons, elephants (3 species), horses (6 species), camels (4 species), sabre-tooth tigers, bears, etc. A warm temperate fauna.	900,000	450,000
First or Nebraskan glacial stage. Alachua, Dunnellon, Bone Valley	Spread of ice-sheets and drift. Includes Pre-Kansan, Nebraskan, and Albertan drifts. A rich Pliocene mammal fauna.	1,200,000	540,000
Pliocene (Blanco)			

Effects of the Glacial Climate

Historical. — During the greater part of the past century, geologists holding strictly to supposed implications of the Laplacian theory of earth origin believed that the earth had been gradually cooling and that it became cold for the first time in the Pleistocene. When, therefore, the first announcements were made, nearly fifty years ago, that a cold climate had been present in the Permian (see p. 428) most of our colleagues of those days could not accept what is now undoubted evidence. The controversy over the origin of the Pleistocene glacial deposits, however, not only made it possible to accept the evidence of the drifts and tills as the result of ice work, but paved the way for the evidence of other and older geologic climates. We now know that such occurred much farther back in the history of the earth, one toward the close of the Paleozoic in the Permian, and two earlier ones in Proterozoic time (pp. 171 and 174). There is evidence of yet other cool periods, and it is probable that we shall learn that the earth has undergone more than four glacial climates (see Fig., p. 445).

Changes in Drainage due to Ice-sheets. — The geologic work done by glaciers in general is described on pages 138 to 144 of Pt. I. Erosion by the continental ice-sheets was unequal and the deposition of the drift materials was especially irregular in distribution. From this it follows that the drainage system of the land was deranged and considerably modified. River valleys were locally filled by the drift to depths ranging up to 400 feet, or partially covered over by the ice, forcing the drainage around its front, as was the case in the middle course of the Ohio River. In fact, the drainage of the glaciated areas was in certain regions revolutionized. Chamberlin and Salisbury state that there were few streams of great length in the areas covered by the ice that were not turned from their old courses for greater or less distances by the ice or the drift. The Ohio and the Missouri — the master streams of the United States marginal to the glaciated area — were built up from previous systems, and a host of their tributaries within the glaciated area suffered marked changes.

Origin of the Great Lakes. — All ice-sheets push out lobes along the preëxisting valleys, and those of the Great Ice Age, especially during the Wisconsin stage, were no exception to this rule. Accordingly, the Keewatin ice-sheet, when it finally melted and retreated across the area of the Great Lakes, had lobes that extended along the ancient valleys (see Fig., p. 135 of Pt. I), scouring them deeper, and leaving in front, as they receded, small lakes that grew to

ever greater proportions and were variable in outline. The first to appear were Lake Chicago, the beginning of Lake Michigan; Lake Saginaw, a part of the future Lake Huron; and Lake Whittlesey, which was of considerably larger extent than its descendant, Lake Erie. At this time, certain of the present small rivers were large, as the St. Croix, Wisconsin, Rock, and Illinois, draining the vast melting waters of the Keewatin ice-field into the Mississippi River. In central New York the "finger lakes" were considerably larger than they are now and their waters for a long time drained into the Susquehanna River, and later through the Mohawk and Hudson rivers. Finally, when the ice had retreated well into Canada, all the Great Lakes were connected far more widely than they are now and drained out eastward through the Ottawa and St. Lawrence valleys. It was this eastward drainage that originated Niagara Falls, which formerly began at Lewiston, New York. It is thought that the making of the gorge by the Niagara River from Lewiston to the present Falls has taken something like 10,000 years (see Fig., p. 268).

Lake Agassiz. — As the ice retreated from Minnesota, the Dakotas, and Manitoba, it left a shallow basin in which another great lake came into existence. Lake Agassiz, as it is called, was once five times as large as Lake Superior, but when the ice-sheet which blocked its northern edge finally melted away, the waters of the lake were drained off, leaving only much smaller lakes, such as Winnipeg, in the deepest parts of its basin. Its existence has been determined from the many raised terraces and sandy beaches made by its waves, and by the broad, flat bottom built of fine silts which were deposited in the lake. This alluvial plain is now one of the richest wheat-growing districts in the world. For other large lakes of Pleistocene time, such as Lakes Lahontan of Nevada and Bonneville of Utah, see pages 87 and 88 of Pt. I.

St. Lawrence Marine Invasion. — When the ice-sheets had finally retreated into Canada and across the St. Lawrence valley and Lake Ontario, the Atlantic Ocean found the glaciated lands depressed, and as a further result of the melting glaciers, the rising waters entered the depression and filled it at least 690 feet deeper than now. This was, therefore, a time of inland or epeiric seas, and it is certain that at some time in the Pleistocene Hudson Bay also appeared, since in the western part of the bay marine strata occur up to a thickness of 600 feet (Tyrrell). In other words, a great part of eastern North America sank under the enormous load of the ice-sheet and when the latter vanished the rising Atlantic flooded deeply Hudson Bay, the St. Lawrence and Ottawa valleys, all of Lake

Ontario and Lake Champlain, and southward to the east of Lake George. Marine shells and the bones of whales and seals are found about Lake Champlain at elevations of up to 440 feet above the present level of the water, at 520 feet near Montreal, and at 480 feet near Ottawa. In the St. Lawrence valley marine fossils are known as far west as Brockville, Ontario (see Pt. I, p. 80, under "relic lakes").

Oscillations of Strand-lines. — At no time in the Pleistocene earlier than the St. Lawrence marine invasion is it known that either the Atlantic or Pacific oceans to any great extent invaded the continent. In other words, North America stood higher above the strand-line than was the case at any time during the Cenozoic.

It is now known, however, that the strand-line was not a constant one during the Pleistocene, but that it oscillated up and down within some hundreds of feet. The cause for this oscillation of sea-level was the subtraction of water as vapor from the oceans and the piling of it upon the continents in the solid form of snow and ice. Drygalski in 1887, and more recently Professor Daly especially, have pointed out that when the great ice-sheet existed on the land the oceanic level between 30° N. and 30° S. must have been depressed to a maximum of not more than 420 feet in the region of the equator, the amount of depression depending upon the extent of the continental ice-sheet. During the Pleistocene warm intervals, the ice of the lands was more or less completely melted away and the water returned to the oceans, thus raising the strand-line. When the ice began to accumulate on the lands, the oceanic level was depressed and the continents enlarged. At these times the lowered strand-lines everywhere began to cut more or less wide shelves or sea terraces into the lands, and when the waters returned it was upon these flooded shelves that the reef-corals began their making of the thick coral-reef limestones.

The land ice also changed the relative levels of land and ocean. When the lands were loaded with the ice-sheets, this great added weight finally depressed them some hundreds of feet. It can be plainly seen that when the Gulf of St. Lawrence and Lakes Champlain and Ontario became inland seas, the region around them was depressed at least 600 feet. Finally, long after the ice had been melted, the depressed land began to rise very slowly, but did not return everywhere to its former level. The lands were thus more or less warped and such a condition brought on the present Great Lakes.

Marked Changes in Europe. — During the Pleistocene, Great Britain remained in connection with northern France (between Calais and Boulogne) and the then eroding outer valleys of the Seine and Somme were flooded by the English Channel. The separation of Great Britain from the continent may have taken place only 5000 years ago and an elevation of 120 feet would again unite them. On the other hand, the Thames and the great Pleistocene Rhine flowed out much farther north, and their former outer plains and valleys are now occupied by the North Sea. This subsidence appeared about 17,000 years ago.

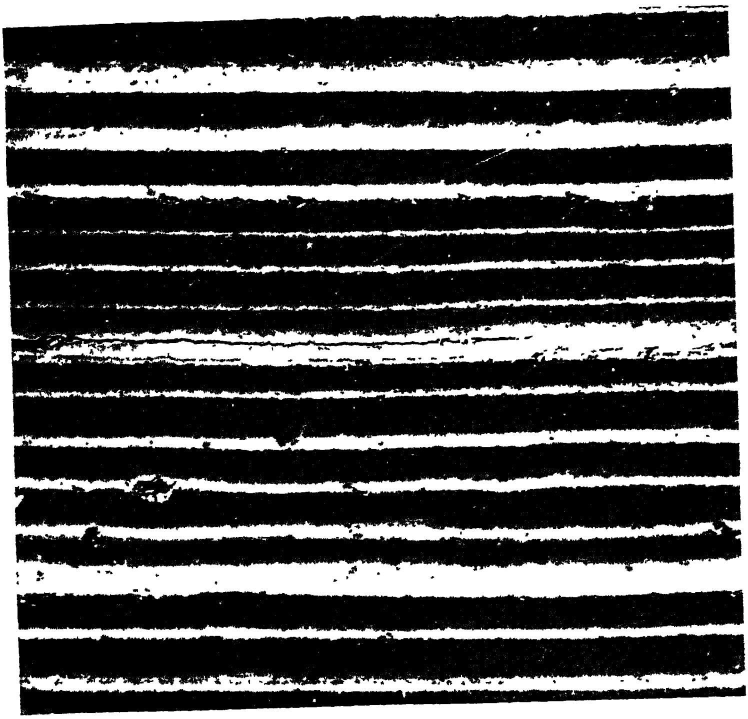

Fig. 229. — Seasonally banded or varved Pleistocene clay, from near Chicopee Falls, Mass. The dark layers are laid down during winters and the lighter ones during summers; the two layers of a year are called a varve. Commonly the summer layers are thicker than in this example. By means of such varved clays, it has been determined that it has taken about 5000 years for the continental glaciers of Pleistocene time to melt back 270 miles to the northwest of Stockholm. About nat. size.

The shallow Baltic Sea is also of latest Pleistocene origin. When the ice left North Germany, the area of the Baltic was still depressed and the North Sea extended across southern Sweden and united the cold Baltic waters with the Arctic Ocean by way of the White Sea. In these waters a certain bivalve (*Yoldia arctica*) was common, and from it the sea has been called the Yoldia sea. On the neighboring lands lived the Dryas flora. As the ice melted farther to the north, Denmark was united to Sweden, northwestern Finland also became land, and in consequence the Baltic depression became for a time an inland fresh-water

lake known as the Ancylus lake, from the snail shell *Ancylus fluviatilis.* This lake did not last long, since the North Sea soon passed across again, depressing Denmark under the so-called Littorina sea, and another slight uplift introduced the present geography.

In southern Europe, great down-sinking of certain basins has been in progress and the Black Sea is of very recent origin. Sicily and Malta were united to Africa, and made of the Mediterranean depression two fresh-water lakes. Later, when the Sicilian-Mâlta bridge was depressed into the depths of the Mediterranean, at about the Middle Pleistocene, connection with the Atlantic was established and the present inland ocean introduced.

Means of Estimating Years since Retreat of Glaciers. — The clays or pellodites in many places in northern North America and Europe are regularly laminated or banded, a fact which attracted the attention of Edward Hitchcock as early as 1841, and led him to say that "probably each layer marks the annual deposit." Nothing came of this suggestion until De Geer in Sweden set to work to demonstrate that banding was due to seasonal changes. A lighter and darker band are laid down each year, and each pair is called a *varve.* The thicker, coarser, and lighter colored band is the spring and summer layer, while the darker, thinner, and finer grained one with more or less of organic matter is the late summer and winter deposit. Counting these layers throughout Sweden, De Geer has determined that Stockholm was under the Pleistocene ice about 9000 years ago, that the ice-sheet began to leave southernmost Sweden 12,000 years ago, and northern Germany 17,000 years ago.

Record of Lands to the South of the Ice-sheets. — The glaciated area has a topographic expression all its own, for here we find the drift in its many forms, erratic stones, large and small, and a striated and scoured ground. Soils are mostly yellowish and thin or absent, and everywhere occur lakes of varying sizes occupying the depressions. In front of the ice-sheets occur the deep old soils that are usually of a reddish color, there is no drift, erratics, or striated ground, the lakes and ponds are comparatively few and due to other causes. The streams are flowing in their old courses, but at lower levels.

The stratigraphic record of the warmer areas of Pleistocene time is scattering, varied, and fragmentary, and it is therefore difficult to determine the chronologic sequence. There are wind deposits of sand and dust along the rivers and the shores of lakes, and in various arid areas occur accumulations of dust (loess); elsewhere there are sediments of rivers and lakes and the deposits made by springs, asphalt pools and fillings of caves and sink-holes often abounding in

bones, peats and marls of marshes and ponds, lavas and ashes in the areas to the west of the Rocky Mountains, and finally the fresh-water, estuarine, and marine accumulations along the borders of the continent. All of these deposits are apt to be thin and localized.

Causes of Glacial Climate

As yet there is no accepted explanation of why the earth from time to time undergoes glacial climates, but it is becoming clearer that they are due rather to a combination of causes than to a single cause. Probably the greatest single factor is high altitude of the continents, with great chains of new mountains (the hypsometric causes) which disturb the general direction and constitution of the air currents (the atmospheric causes) and the ocean currents as well.

Hypothesis of Polar Wandering. — It has often been suggested that the axis of the earth has shifted and that the north pole in Pleistocene time was 15° or 20° south of its present position. To explain the equatorial glaciation of Permian time some writers have shifted the north pole to the region of Mexico, and the south pole to the Indian Ocean; even if this were possible, however, the distribution of the ice-fields did not center about these imaginary poles. As the earth is essentially as rigid as steel, the dynamic conditions in such a mass would not permit of such changes without leaving a record of them in the structure of the earth-shell. There are no such records discernible. Moreover, it was long ago demonstrated mathematically by G. H. Darwin that migrations of the axis of the earth sufficiently extensive to be of geological importance have not occurred. "It would appear," says Barrell, "that the assumption of polar wandering as a cause of climatic change and organic migration is as gratuitous as an assumption of a changing earth orbit in defiance of the laws of celestial mechanics."

Effects of Continental Emergence. — Of the four known glacial climates of geologic history, at least three (early Proterozoic, Permian, Pleistocene) occurred during or directly after times of intensive mountain making, while the fourth (late Proterozoic) apparently also followed a time of elevation. The Laramide Revolution at the close of the Mesozoic, on the other hand, was not accompanied by a glacial climate, but only by a cooler one, with alpine glaciers in Colorado; the glacial conditions in central Australia are earlier. The cooled Lias time (p. 512) also followed a mountain-making period. We therefore see that the known cooled or cold climates occurred during or immediately followed periods of marked mountain making.

Again, the three marked glacial climates of late Proterozoic, Permian, and Pleistocene times and the cooled climates of the Lias and Cretaceous all fall in with times when the continents were more or less highly emergent. There were no cold climates when the continents were flooded by the oceans, and it may be added that the periods of

wide-spread limestone making preceded and followed, but did not accompany, the reduced climates (see Fig., p. 445).

Effect of Volcanic Ash in Atmosphere. — Humphreys has shown that volcanic dust, shot very high above the cloud region of the earth's atmosphere, where it may continue to float for months, does appreciably reduce the temperature at the surface of the globe. The greatest amount of dust in the atmosphere should, therefore, coincide with the times when the volcanoes are most active, or when mountains are being elevated. An analysis of the climates during these times shows that while they may have been thus cooled, the dust in the higher atmosphere of the earth does not appear to have been a primary factor in bringing on glacial periods. On the other hand, it can not be denied that such periodically formed blankets against the sun's radiation may have been a contributory cause in cooling climates during some of the periods when the continents were highly emergent.

Effects of Oceanic Spreading. — The life of the seas of the past indicates vast stretches of time of mild to warm and equable temperatures, with but slight zonal differences between the equator and the poles. These were punctuated by short but decisive periods of cooled waters and great mortality, followed by quick evolution and the rise of new stocks. On the land the story of the climatic changes is different, but in general the equability of the temperature simulated that of the oceanic areas. The lands were, however, periodically inundated by warm waters, causing insular climates that were milder and moister. With the vanishing of the floods, somewhat cooler and certainly drier climates were produced. (See Fig., p. 445.)

When to these factors is added the effect upon the climate of the periodic rising of mountain chains, it is apparent that the lands must have had constantly varying climates. In general, the temperature fluctuations seem to have been slight, but geographically the climates varied between mild to warm pluvial and mild to cool arid. Finally, it must not be forgotten that when the lands were highly emergent, the formerly isolated lands were connected by land bridges that more or less altered the oceanic water circulation and therefore the local temperature.

Effect of Carbon Dioxide in Atmosphere. — A great deal has been written about the supply and consumption of the carbonic acid of the air as the primary cause for the storage of warmth by the atmospheric blanket. A greater supply of carbon dioxide is said to cause increase of temperature, and a marked subtraction of it to bring on a glacial climate (see Pt. I, p. 92, and Pt. II, p. 438). This aspect

of the climatic problem is altogether too large and important to be entered upon here. It is permissible to state, however, that the glacial climates are irregular in their geologic appearance, are variable latitudinally, as is seen in the geographic distribution of the tillites between the poles and the equatorial region, and finally that they appear in geologic time as if suddenly introduced. These differences do not seem to be conditioned in the main by a greater or smaller amount of carbon dioxide in the atmosphere, for if this gas is so strong a controlling factor, it would seem that at least the glacial climates should not be of such quick development. On the other hand, an enormous amount of carbon dioxide was consumed in the vast limestones and coals of the Cretaceous, with no general glacial climate as a result; though it must be admitted that the great limestone and vaster coal accumulations of the Pennsylvanian were followed by the Permian glaciation. Again, it may be stated that the Pleistocene cold period was preceded in the Miocene and Pliocene by far smaller areas of known accumulations of limestone and coal than during either the Pennsylvanian or Cretaceous, and yet a severe glacial climate followed.

Effect of Sun's Warmth on Earth. — The heat waves of the sun radiating into space warm the earth's surface more than the air, because the former is an absorbing surface. Nearest the earth's surface the air is laden with water-vapor, another absorbing layer. At high altitudes the free air has contact with no absorbing surface to warm it, and as it transmits sun-rays with great freedom, it derives only a little heat from them directly. It contains, moreover, ozone, carbon dioxide, and water-vapor, which freely radiate long-wave rays and thus dissipate into space the heat gained. Consequently the high air is cold, and cools whatever it blows upon. Its cooling action on the surfaces of mountains is greater on account of the high winds which prevail. Abbot attributes the coolness of the free upper air to its transparency, its considerable radiating capacity, and its expansion; the coolness of the rugged mountains to their contours, and to the contact of the cool winds; the coolness of the elevated inland plateaus to the dryness of the air above them, at the same time recognizing that all three are receiving more intense rays from the sun than is the earth's surface in general.

Effect of Variation in Solar Energy. — As all of the appreciable heat of the atmosphere is derived from the sun, it is necessary to examine this source to see if the quantity varies. It is now well known through the work of Langley and Abbot that the sun is a slightly variable star and that the output of radiation outside of the

atmosphere of the earth is variable within limits of from 5 to 10 per cent in quantity and in irregular periods of from five to ten days. Abbot says that a solar change of 5 per cent, continued for six months, might well alter the mean temperature of inland stations 3°–6° F., which would make the difference between an unusually hot and an unusually cold season. Moreover, Huntington states that five authorities on glaciation have concluded that if the mean temperature of the earth were to fall 9° or 11° F. and were to remain thus low for a sufficient length of time, meteorological conditions would be so altered that a large part of North America would be covered with ice down to about the fortieth degree of latitude, and Europe would suffer a corresponding glaciation. Of course there is no direct evidence to show that the intensity of solar radiations has varied so greatly in past times. That it does vary in a minor degree, however, has been shown. According to Abbot, sun-spots are at times one twentieth of the sun's diameter, or five times that of the earth, and sun-spot groups at times spread over more than one tenth of the sun's diameter. Curiously, the earth's surface air temperature is on the whole lower at sun-spot maxima than at sun-spot minima. This being so, Huntington postulates that at certain times the sun may have been stimulated to unusual activity, just as it is to-day when we have periods of unusually numerous sun-spots, but to a greater degree. During the times of great but short stimulation, the sun's atmosphere would also be laden with much dust, shutting in the solar heat and cooling the thermal blanket of the earth to the extent of bringing on a glacial climate. As the solar atmosphere became clearer and more and more of its heat radiated into space, the earth would become warmer, giving rise to a long interglacial stage of usual warmth or aridity. Finally it should be added that as cold climates appear during or shortly after excessive mountain making on the earth, crustal unrest and reduced climates appear to occur simultaneously with the hypothetical stimulations of the sun.

Conclusions. — Briefly, then, we may conclude that the markedly varying climates of the past seem to have been due primarily to periodic changes in the sun and in the topographic form of the earth's surface, plus variations in the amount of heat stored by the oceans. The transformed face of the earth altered the configuration of the continents and oceans, the air currents (moist or dry), the oceanic currents (warm, mild, or cool), and the volcanic ash content of the atmosphere. The causation for the warmer interglacial climates may lie in oscillations of solar energy.

Life of the Pleistocene

The most interesting life of the Pleistocene is naturally the mammalian, and even though it is as a rule very fragmentary, it is so widely scattered as to give a fair idea of its extent. In fact, as Scott says, with all its gaps, the record is impressive. The human history will be presented in the next chapter.

The most striking of the Pleistocene mammals in North America were the three species of elephants and the one of mastodon. The last named, *Mammut americanum*, migrated from Siberia into Alaska, and ranged over nearly all of the United States and southern Canada (Fig. *A*, p. 643). It was most abundant in the forested regions and rarer in the plains country, and persisted so long that the animal may have been hunted to extermination by the red men.

Of the elephants, the most interesting and widely distributed was the Siberian woolly mammoth (*Elephas primigenius*), an animal of the cold climate, standing about 9 feet tall at the shoulders, and coming to North America by way of Alaska (Fig. *C*, p. 643). It ranged from the far north through British Columbia into the United States and across to the Atlantic Coast. The mammoth also migrated from Asia into Europe and was there hunted by Pleistocene man (see Fig., p. 683). It died out in North America late in Pleistocene time.

Closely related to the above form was the Columbian elephant (*Elephas columbi*), of taller stature, being 11 feet at the shoulders (Fig. *D*, p. 643). It lived during the earlier half of Pleistocene time in the warmer portions of North America, roaming over the whole United States and the high plains of Mexico. The third species was the huge Imperial elephant (*Elephas imperator*), said to attain to 13 feet and 6 inches in height (Fig. *B*, p. 643). It was probably a plains animal that survived from Pliocene times and died out in the Middle Pleistocene. Its range was western America from Nebraska to Mexico City.

The horses were exceedingly numerous in the earlier Pleistocene, and roamed, apparently in great herds, all over Mexico and the United States and even into Alaska. There were at least ten species of *Equus*, one no larger than the smallest pony, others larger than the heaviest modern draft-horses. They were descendants of American Pliocene horses and all died out during the Pleistocene.

Of peccaries there was an abundance, and there were also camels and llamas. During the times of glaciation the caribou ranged south into Pennsylvania and musk-oxen into Utah, Arkansas, and Ohio. The modern moose was present in the western half of the continent,

Fig. 230.—Giant sloth (*Megatherium*) and two kinds of glyptodonts (*Glyptodon* above, *Dœdicurus* below), from the Pleistocene (Pampean) of Argentina. After J. Smit, from Knipe's *Nebula to Man*.

but the stag-moose (*Cervalces scotti*) was a late arrival during the last ice invasion. Other ruminants related to the musk-ox occurred earlier in the period, and of bison there were at least seven kinds, ranging from Florida to Alaska, one species (*Bison latifrons*) with a horn spread of 6 feet.

Among the carnivores, the most formidable was the great sabre-tooth tiger (*Smilodon*), which lived over the greater part of the United States. Of rodents the most interesting was the late Pleistocene giant beaver (*Castoroides ohioensis*), as large as a black bear.

The ground-sloths were represented by a large and widely spread form, *Megalonyx*, first discovered and named by President Thomas Jefferson. The giant southern form *Megatherium* (Fig., p. 665), had a body as large as that of an elephant, though shorter in limb, while the oldest and smallest of the sloths was *Mylodon*.

Collateral Reading

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O. P. Hay, The Pleistocene of North America and its Vertebrated Animals from the States east of the Mississippi River and from the Canadian Provinces east of longitude 95°. Carnegie Institution of Washington, Publication No. 322, 1923.

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CHAPTER XLVI

MAN'S PLACE IN NATURE

The title of this chapter is the same as that of one of Huxley's famous books, in which he states: "The question of questions for mankind — the problem which underlies all others, and is more deeply interesting than any other — is the ascertainment of the place which Man occupies in nature and of his relations to the universe of things." Some of us may not be inclined to study man as a part of nature, but whatever our prejudices, man's physical welfare and intellectual uplift into ever higher and higher states of civilization are unquestionably bound up with the ascertaining of our relations to the rest of nature. "Man is the paragon of animals, the climax of evolution" (Conklin). Our personal health and the correct understanding of our mental workings, combined with a study of our intercommunal relationships with the rest of nature, can only redound to the welfare of humanity. We need to study what man means in the Cosmos.

Fig. 231. — Profile view of the head of *Pithecanthropus*, the Java ape-man, after a model by J. H. McGregor. From Osborn's *Men of the Old Stone Age*, 1915.

Man seems to us so very different from all the animals that we can not believe him to be related to them at all, and prefer to regard him as standing isolated and alone, something quite apart from all

organisms. When, however, we begin to study his body and compare it, organ by organ, with that of other animals, we see that his isolation disappears, and that it is the thick veil of civilization in which he has so completely hidden himself that misleads us regarding his true position in the animal kingdom.

Comparisons between Man and the Other Primates. — Linnæus in his classification of animals placed man at the head of them all, hence the term Primates from the Latin *primus* or *first.* The most primitive Primates are the lemurs, and the higher forms are the anthropoids (means *man* and *form*), because in them the brain is more highly developed than in any other animals. The latter division includes the New World monkeys, the Old World monkeys (also baboons, mandrills, macaques), the gibbons and apes, and man.

Fig. 232. — Front view of the head of *Pithecanthropus*, the Java ape-man, after a model by J. H. McGregor. From Osborn's *Men of the Old Stone Age*, 1915.

The mean *stature* of present-day Europeans is 5 feet 6 inches, and we shall see later on that the oldest fossil men vary between this size and 5 feet 4 inches. Men of 6 feet in height did not appear until toward the close of the Glacial Period (Pleistocene) in the Aurignacian race of France. We are, therefore, not descended from a race of giants, but rather are we tending toward a taller stature.

The erect *posture* of man is also of ancient origin, for it is fully developed in the oldest fossil men, and probably had its beginning in the gibbons of Pliocene time. It is, however, not so much in his posture that man differs from the large anthropoids as in his manner of progression. He is adapted to living on the ground, " an adaptation which allowed him to escape beyond the limits of forests and occupy the whole world." It is, therefore, in the construction of the legs and in the setting of the entire foot upon the ground (plantigrady) that man varies much from the greater apes, and as the human leg and foot are already developed in the oldest known fossil man, it is

clear that this evolution also took place prior to the Pleistocene. It was during this earlier evolution of man that the great toe, set like a thumb and used as a grasping organ, was changed into the non-grasping toe of living man. The human type of leg and foot was, then, developed long before the human brain came to be as we see it now, for in the oldest fossil ape-man (*Pithecanthropus*) the brain is little more than half the size of that in living man. The large brain of man appears to be his latest acquisition; his foot, leg, and plantigrade gait are older, his size of body older still, and his erect posture quite an ancient character.

"The *skeleton* of the gorilla is not at all human in appearance, the great crests on the skull, the massive jaws and face, the long stout arms, the short lower limbs with a thumb-like great toe, seem to assure us that even the most man-like of apes is a long way off from man himself. Yet when we look more closely we see that every bone of man's body is present in the gorilla; they occupy exactly the same place in the skeleton; each bone shows the same leading features; the differences relate merely to proportion, size, and detail. When we look at the skull of the young gorilla, before the massive, brute-like crests have appeared, the human resemblance is more marked. In the skulls of the adult chimpanzee, these cranial ridges, which are developed to give attachment to the great muscles of mastication, are much smaller than in the gorilla. In the orang they are intermediate in size." (Keith.)

Between the higher apes just mentioned, which Huxley refers to as "blurred copies" of man, and the smaller and lower apes, the gibbons, there is another break in the evolutionary steps quite as marked as the one between man and the great anthropoids. The head and body are much smaller, there are the same bones set together in the same order, but the proportions are different. The gibbons are of early Pliocene origin and have clung to the ancestral form more closely than any of the other apes. Between the gibbons and the monkeys there is a wider gulf than any we have so far seen, yet we can not well say the one is higher than the other. In certain features we see that the gibbons are related to the Old World monkeys, in others to those of the New World; we believe that there must be extinct ancestral gibbons which, did we know them, would show us that these three forms of primates have all arisen from a common stock at a long past period of the world's history. Among the American monkeys we find quite small and low forms, such as the marmoset, which take us a little way toward the lemurs. "If at first we had seen the skeleton of man placed side by side with that of the

tiny marmoset we would have denied that there could be any possibility of a common origin for these two, but when we pass from the one to the other through a series which, while showing many breaks, leads us step by step from the one to the other, we begin to see that the miracle of man's primate origin is not so impossible as it appears at first." (Keith.)

The *brain* of the higher vertebrates consists of two main parts, a lower and hinder division known as the cerebellum, and an upper part, the cerebrum, that is again divided into right and left hemispheres. In the mammals previous to the Oligocene the lower brain is the larger, but beginning with this time the upper brain, where reason and memory are located, increases rapidly in size in nearly all stocks and finally is considerably greater than the entire cerebellum, and almost covers it.

In man the size of the brain depends to a certain extent upon the bulk of the body; tall men on the average have larger brains than small men. It therefore does not hold true that bulkier men with larger brains are more able than smaller ones with less weighty brains, though the fact remains that many of the world's most famous men had large heads and big brains. The brains of Bismarck and Cuvier each weighed about 66 ounces, that of the Russian novelist Turgenieff nearly 75 ounces, while that of Gambetta, the French statesman, weighed about 42 ounces, and that of Leibnitz, a great German philosopher and mathematician, less than 45 ounces. In adult men the weight of the brain varies between 65 and 34 ounces (average 49), and in women, due to their smaller size, it is between 56 and 31 ounces (average 44) or about 12 per cent lighter than in man. When the brain is contrasted with the entire weight of the body it is about as 1 to 45.

In the smallest gorilla the brain weighs 15 ounces and in the largest 20 ounces, while the weight of the entire body at maturity varies between 200 and 360 pounds, giving an average ratio of about 1 to 250. At birth the human brain weighs between 10 and 11 ounces, or about one fifth its size at maturity. By the end of the second year the human brain has attained two thirds of its adult size, and has then reached the same relative degree of development that the anthropoid has at birth. Maximum size of the brain in man is reached at about the twentieth year, and it then slowly loses weight into old age, when decrease is more rapid. "Man's prime is not a period," says Karl Pearson, "it is merely a point of time."

Evolution of the Human Brain. — According to Elliot Smith, man's most distinctive attribute, namely, higher-mentality, began even before the Pleisto-

cene. At the basis of this mental growth lay *vision*, the fundamental stimulus leading to inquisitiveness. This trend probably began with the lemurs of late Mesozoic time, since good vision in an arboreal environment is a prime requisite. It awakened the animal's curiosity concerning the things around it, prompting it to handle them. Thus were developed increased skill in movement, greater tactile sense, and better muscular correlations, and through these an empirical knowledge of the environing world. These changes reacted on the brain and through its development was opened " the way for the wider vision and the power of looking forward that are so pre-eminently distinctive of the human intellect". " Our common speech is permeated with the symbolism that proclaims the influence of vision in our intellectual life."

Later was developed, through seeing, concentration of attention, and finally mental concentration, learning through trial and error. With the acquisition of this new power of learning by experimentation, events in the world around the

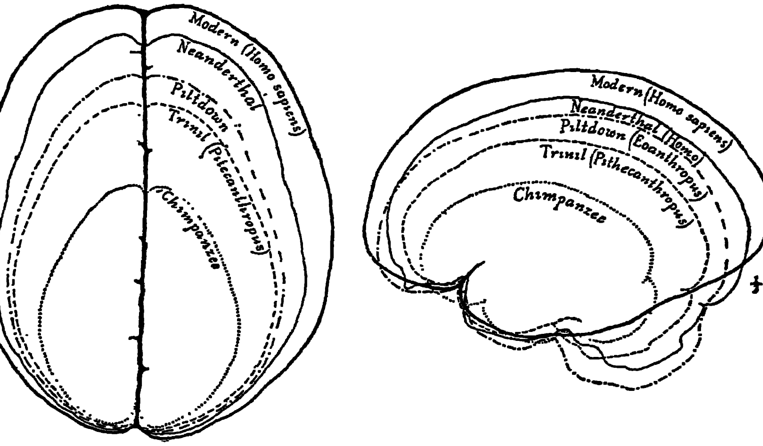

Fig. 233. — Diagrams from the top and side of the brains of chimpanzee and ancient and modern man, showing in outline their relative sizes and shapes. From Osborn's *Men of the Old Stone Age*, 1915.

primates took on a fuller meaning; and this enriched all experience, not merely that which appealed to the senses of sight and touch, but hearing also. Better hearing eventually led to vocal expression, an achievement that distinguishes the human line at least as early as *Pithecanthropus* and *Eoanthropus*. " Speech exerted the most profound influence upon human behaviour, for it made it possible for most men to become subject to tradition and to acquire knowledge from their fellows without the necessity of thinking and devising of their own initiative."

Geologic Rise of Primates. — The oldest lemurs appear in the American Paleocene (Fort Union) and Eocene (Wasatch) in small forms very much like the tarsier living in Madagascar. Diminutive monkeys appear a little later (Bridger), but before the close of the Eocene all primates seem to have become extinct in North America.

The Old World monkeys appear to have had an independent origin in the lemurs, and it was out of the former that the apes arose. In the later Oligocene of Egypt appears the oldest ape (*Propliopithecus*). apparently the progenitor of all later anthropoids. This was a small animal which spread in early Miocene time into Europe and there gave rise to the larger apes of the western part of that continent (*Pliopithecus* into *Dryopithecus*). It is, then, since Middle Miocene time that we may expect the rise of the human stock. The great-bodied primates of about this time probably divided into two independently evolving stocks, the one retaining the ancestral arboreal habitat, the other taking more and more to the ground. The former line of evolution gave rise to the gorilla and chimpanzee of Africa and the orang of Borneo and Sumatra, while the terrestrial stock developed into the ancestry of man. Living man is known as *Homo sapiens* (reasoning man) and in his varied geographical races is distributed over the entire earth. All men are but varieties of this one species, the negroid races being the most primitive. As we go back into the Pleistocene we meet with other human species, more and more primitive, and finally with the ape-man (*Pithecanthropus*) of Java.

Embryology of Man. — All animals, however simple or complex in construction, begin in a single cell with a nucleus, and the human species begins in the same way. But the human ovum does not become a wonderful growing microcosm unfolding ancestral characteristics until it is fertilized by the sperm. The Miracle of Birth lies in the Mystery of Union (Brian Hooker). All the higher organisms begin in comparative simplicity and develop through growth into greater complexity. The human ovum or egg, considered as a cell, is large, but actually is so small that about 125 of them when laid side by side have a length of one inch only; while the male or sperm cell that enters the ovum and starts its development is vastly smaller. Therefore, the tiny microcosm of living female and male matter has within itself the potentialities of the future man or woman, and the individual during its development and mature existence reveals not only the characters of its direct human ancestors but something of its animal line of succession as well. It is during the first three months of fœtal development that all of the great changes or transformations take place and that all parts of the body are formed. It is, in fact, during this early development that the human fœtus strikingly resembles that of the lower animals. The remaining six months of gestation are those of growth and maturation.

The fertilized human ovum in its development divides into two cells, these again divide, and this division of cells continues, the cells arranging themselves in a definite manner into tissues and organs. We can not follow here all the early transformations, and need only state that at about the third week of growth the body cavity begins to appear, that is, the cavities which enclose the organs of the thorax and abdomen. The fœtus is then in the cœlomate or vermian stage, that is, it now has a true body cavity and is therefore higher in construction than the cœlenterate animals (see p. 282). Already in the second week the worm-like

embryo begins to have a segmented body and in the following week appear four grooves on the neck of the fœtus. These grooves represent the gill slits of fishes, and the heart then also has the construction seen in fishes, that is, is two-chambered. No functional gills are actually developed, however, but the structure of these vestigial gills is a clear hint that the mammalian and human lines had ancestors with this type of breathing organ, that is, among the fishes and amphibians. By the sixth week all outward appearance of the gill slits is gone; the fœtus has passed from the gilled to the lunged stage, and the fish-like heart with its two chambers has changed into the three-chambered heart seen in the amphibia, and then into the four-chambered one of mammals. The heart begins to beat in the gilled stage, but the lungs do not come into use until birth. Before then the placenta serves the purpose of respiration (see Fig., p. 415).

Conclusions. — "Identical in the physical processes by which he originates — identical in the early stages of his formation — identical in the mode of his nutrition before and after birth, with the animals which lie immediately below him in the scale — Man, if his adult and perfect structure be compared with theirs, exhibits, as might be expected, a marvelous likeness of organization. . . . And thus the sagacious foresight of the great lawgiver of systematic zoölogy, Linnæus, becomes justified, and a century of anatomical research brings us back to his conclusion, that Man is a member of the same order as the apes." (Huxley.)

Men of the Old Stone Age

The time of the Old Stone Age is that of the later Pliocene and practically all of the Pleistocene. Everywhere the men of this time were fierce hunters and makers of but the crudest of stone implements. Probably originating in the rising highlands centering about the Himalayas, primitive man spread into the lower and warmer parts of Europe and Africa, not through directive migration, but as other animals do, through radial spreading and adaptation.

Stone Implements. — In many places have been found large and small stones, chiefly of flint, that have rudely chipped edges and resemble weapons made by primitive man. These are known as *eoliths*, "dawn stones." They are found in strata of various ages as far back as the Oligocene, a time when no human being existed making stone implements. The older "eoliths" are flints fractured by nature through such causes as rock pressure, temperature changes, or wave-pounding in the littoral of the sea.

In the ape-man, with dawning intellect, pebbles may have at first served as missiles or even as hammers. The mere striking together of stones, and especially the brittle flints, would lead to the discernment of cutting edges and the production of flakes that could be used

for scraping, sawing, and sundering flesh and skins. At first such implements would be no better than those made by nature, and to separate the artifacts from those made through natural causes is most difficult. There is now, however, no longer any doubt about man-made eoliths and evidence of man-made fires occurring in the Upper Pliocene strata of southeastern England (Foxhall, Ipswich, Suffolk). Younger eoliths, of the First Glacial time, occur at Cromer, Norfolk. These are older than the oldest known human bones.

The oldest well made human artifacts are known as *paleoliths*, and among these the older ones (Paleolithic) are very crude in workmanship (Fig., p. 677). They are nodules of flint, reduced to the required shape and size by flaking with the hammer-stone, by means of oblique blows delivered to the right and left. These crude artifacts are short, thick, and irregular in form, with variable but comparatively small conchoidal fractures where the flakes were detached. The flakes obtained as by-products could also be used for small implements. For the greater part they are rude scrapers and knives, and none appear to be weapons of the chase, though their makers may have had rude wooden spears. The Neandertal men (see p. 681) showed far more skill in the making of their artifacts, for they knocked quite large thin flakes (up to 7 inches in length) from the flint nodules and then trimmed these into the desired shape for lance-heads by finer secondary and tertiary chipping. These tools were made by the men of the Old Stone Age, men who were learning how to hunt animals for food and to defend themselves by their greater skill in the invention and use of improved killing devices.

A human chronology based on the state of the stone culture can not, however, be expressive of a correct human progression, since the Tasmanians when discovered were making Paleolithic implements, while the North American Indians had tools of a still better type (Neolithic), and their discoverers had advanced into a high stage of civilization. Therefore long after some of the ancient hunters were making paleoliths, others remained in the Eolithic stage. The makers of paleoliths also learned to make implements and ornaments out of bone and horn, but none of these peoples had risen to the making of pottery or the herding of cattle and the raising of food plants. Man was still the hunter.

The Ape-man of Java. — In 1891 there was discovered at Trinil, Java, in volcanic material (lapilli) a great quantity of mammalian bones, of species which are now all extinct in that region. Among these were the remains of the oldest known bones of ancient man.

The geologic age of the fossils is somewhat uncertain, but Berry holds that the associated plants are early Pleistocene in time, since none are yet extinct. This flora is not insular, but is continental in character. It was an upland evergreen forest flora, of a wet tropical climate with a mean annual temperature of about 70° F. Trinil man lived " during the first or second time of glaciation in Europe."

The human remains consist of the upper part of the skull, or cranial vault, three molar teeth, and the entire left femur. Dubois, the discoverer, named this human being *Pithecanthropus erectus*, which means *the ape-man who walked erect* (Figs., pp. 667, 668, and below). It is interesting to note here that long before Dubois' discovery, Haeckel, on theoretic grounds, predicted the finding of such an ape-

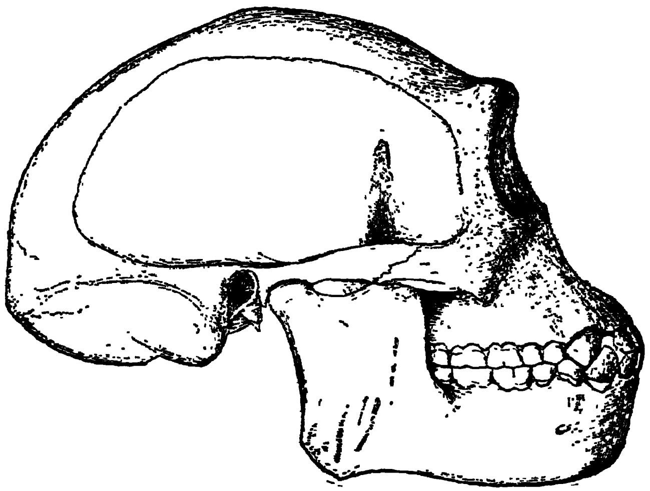

Fig. 234. — Skull of *Pithecanthropus*, the ape-man, as restored by Dubois.

man, for whom he coined the name *Pithecanthropus*. The skull is of the long-headed (dolichocephalic) type, and has a low crown with prominent brow-ridges, the forehead is more receding than that of the chimpanzee, and the volume of the brain cavity is approximately 28 ounces. The largest cranial capacity in the higher apes does not exceed 20 ounces, while that of a normal living human is never less than 30 ounces. As the average human brain has a capacity of about 49 ounces, it is seen that *Pithecanthropus* must be included within the human family, and in his mental evolution had risen far higher than halfway between the apes and modern man. He is probably not in the direct line to the higher types of man, but represents a specialized and unprogressive branch which became extinct in the Pleistocene (Smith). The femur is distinctly human,

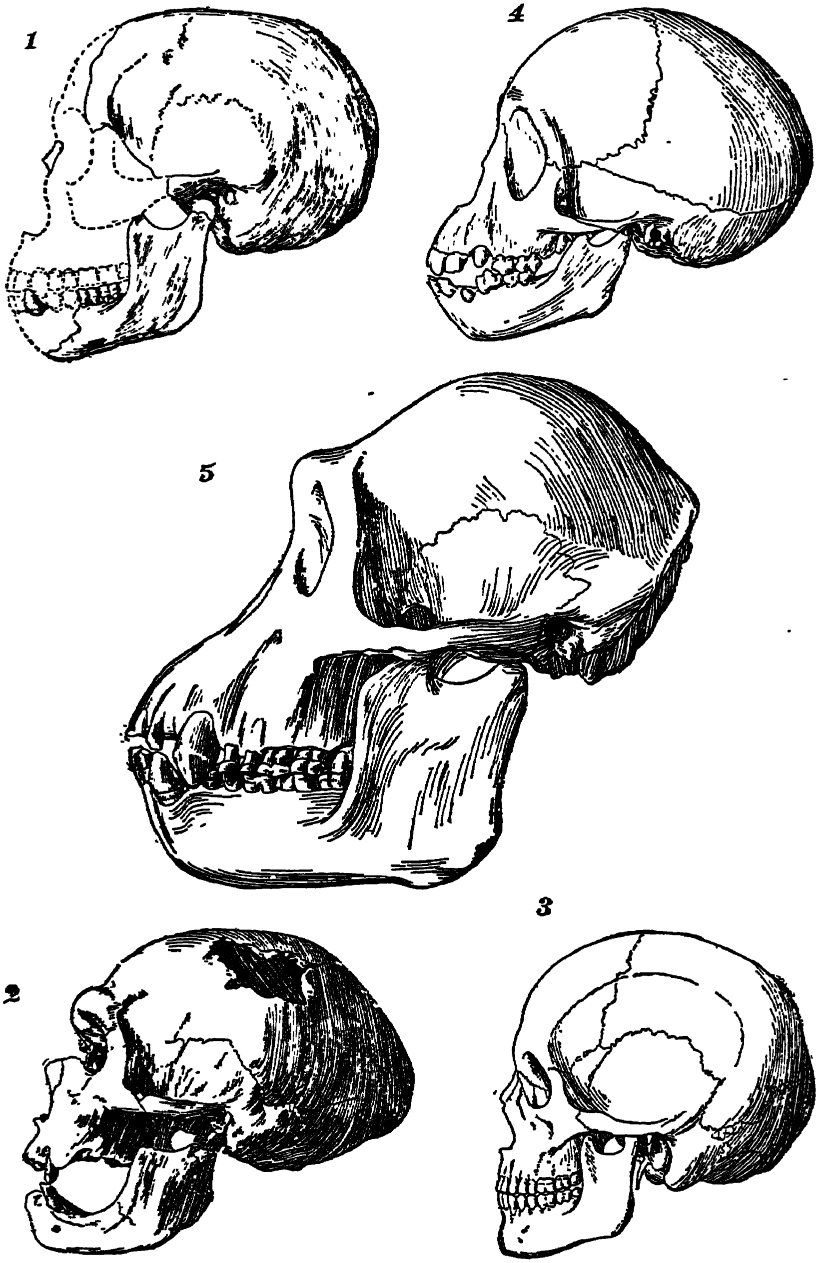

Plate 46. — Skulls of man and apes. 1, *Eoanthropus;* 2, Neandertal or Mousterian man; 3, modern human; 4, young chimpanzee without brow-ridges and more like *Eoanthropus;* 5, adult chimpanzee with marked brow-ridges and more like Neandertal man. After Woodward, from British Museum Guide.

of a being that walked more or less erect, and in all probability possessed a foot very much like that of living man. The brain cavity also shows that the ape-man had probably acquired the rudiments of vocal speech. *Pithecanthropus* is estimated to have stood 5 feet 6 inches high.

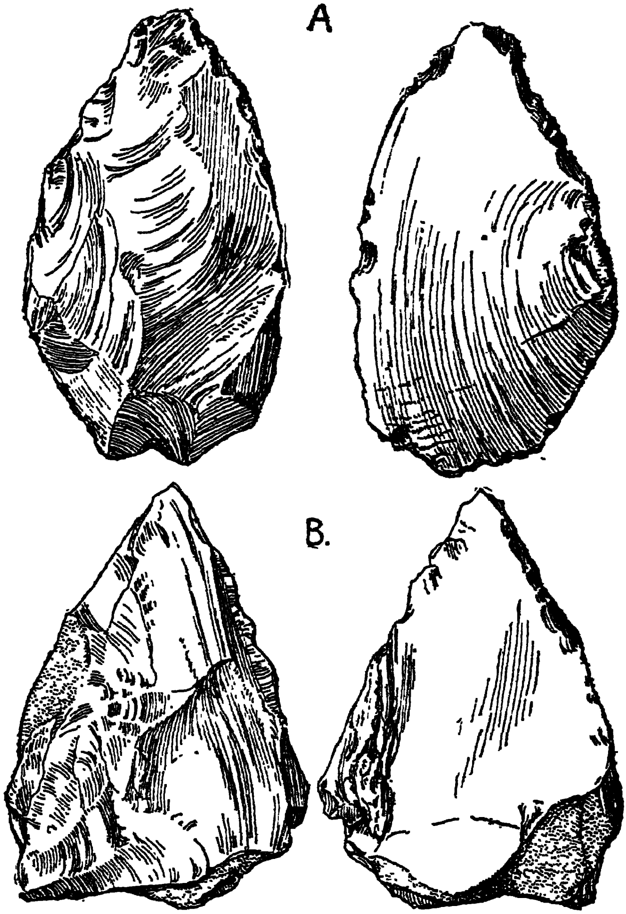

Fig. 235. — Two primitive Paleolithic flint implements associated with *Eoanthropus*, two-thirds nat. size. Each shows a coarsely flaked face and a simply flaked face. After Woodward, from British Museum Guide.

Eoanthropus of England. — In 1913 there was brought together the greater part of a human skull and jaw found in the plateau gravels at Piltdown, near Fletching, in Sussex, England. These remains are the oldest known of the human family in Europe and have been named the " dawn man " or *Eoanthropus*. The fragments have

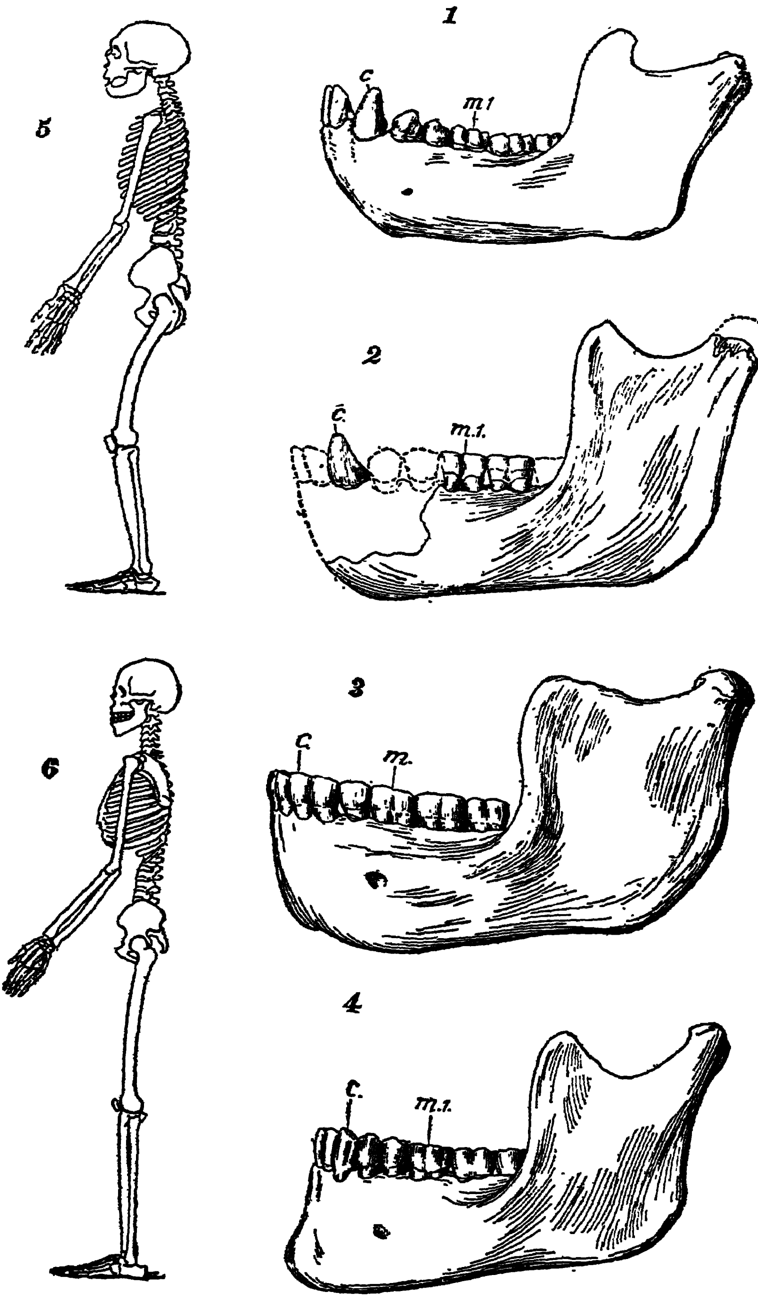

Plate 47. — Left outer sides of lower jaw of chimpanzee (1), *Eoanthropus* (2), Heidelberg man (3), and modern man (4). *c*, canine teeth; *m.* 1, first molar teeth. Diagrammatic restoration by Boule of skeleton of Neandertal man (5), and of living Australian man (6). After Woodward, from British Museum Guide.

been carefully set together and the greater part of the skull restored by Smith Woodward of the British Museum (Pl., p. 676, Fig. 1, and Pl., p. 678, Fig. 2). The lower part of the face is decidedly prognathous or "snouty," the forehead, though narrow, is not receding, and is as steep as in modern man, the brow-ridges are feeble, and the brain case is very thick, with a cavity content of nearly 43 ounces. The size of the brain, therefore, compares favorably with that of the average European, which has a content of about 49 ounces. The skull is low in proportion to length (brachycephalic), and even though it is archaic, is truly human; but the chinless lower jaw, with its large canines, is distinctly simian and very much like that of a young chimpanzee, and the neck is very thick. The jaw bone of the dawn man is, in fact, so decidedly like that of a chimpanzee that good authority pronounced it to be such, accidentally associated with the human skull. The subsequent discovery of a similar association, however, seems to render that theory untenable. No other ape bones have ever been found in England. This strange creature, therefore, combines a human brain case with an ape's jaw. It was probably able to speak, though in a rudimentary fashion.

The prognathous face and powerful jaws, with their large teeth, especially the canines, show that *Eoanthropus* was a human brute, hunting and defending himself in the main with his fearful biting mouth. He was still a primitive slayer, though keener than any of his animal associates, and was destined through the manufacture of better implements to become a hunter of a higher order.

With *Eoanthropus* were associated very ancient types of Paleolithic implements (Fig., p. 677). The age of the plateau gravels is thought to be of the second interglacial warm time, when the hippopotamus lived in England; this is about early Middle Pleistocene (Fig., p. 653). Osborn, however, believes that the age may be Pliocene.

Attention should be directed here to Smith Woodward's statements that at least one very low type of man with a high forehead was in existence in western Europe long before the low-browed Neandertal man (p. 680) became widely spread in this region. Accordingly he inclines to the theory that the Neandertal race was a degenerate offshoot of early man and probably became extinct, while surviving modern man may have arisen directly from the primitive source of which the Piltdown skull provides the first discovered evidence.

Heidelberg Man. — In 1907, at Mauer, Germany, not far from Heidelberg, there was found a well-preserved human jaw with all

of the teeth (Pl., p. 678, Fig. 3). It was buried about 80 feet beneath the surface in river-deposited sand of early Middle Pleistocene age and possibly of the second interglacial warm time (Fig., p. 653). More recently eoliths have been found in the same stratum that held the jaw. The teeth, while powerful, are distinctly human, but the jaw bone is massive and broad and clearly more like that of an anthropoid ape. This man, known as *Paleanthropus heidelbergensis*, had no chin and was probably most closely related to *Eoanthropus*.

Neandertal Man. — In 1856 most interesting human remains were found in a cave in the little valley known as the Neandertal, lying between Düsseldorf and Elberfeld, Germany. Since then more

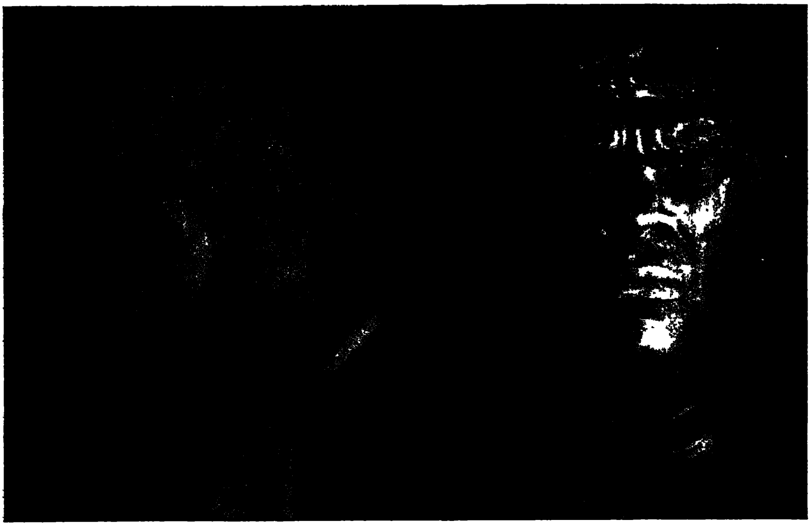

Fig. 236. — Restoration of the head of Neandertal man. Modeled by Mrs. H. Hyatt Mayer.

than fifteen other men, women, and children of this race have been found in caves and rock shelters in Belgium, France, Gibraltar, and Krapina in Croatia (Pl., p. 676, Fig. 2, and Pl., p. 678, Fig. 5). Their implements, however, are found scattered throughout western Europe and eastward into Poland, the Crimea, and Asia Minor. In France these people are known as the Mousterians and they are thought to have been the first who dwelt in caves. They lived during the last glacial episode when the climate was cool and finally cold, a time estimated to be anywhere from 60,000 to 150,000 years ago. It was the time of the bison, horse, reindeer, and mammoth, on all of which the Neandertal men subsisted. The race lived for a long time geologically.

The Neandertal people (*Homo primigenius*) were a savage-looking race of stout build, short stature, averaging about 5 feet 3 or 4 inches, with legs slightly bent at the knee, and with disproportionately large heads (Pl., p. 678, Fig. 5, and Fig., p. 680). They made fairly good stone implements and knew how to kindle a fire, for hearths occur in their cave abodes. The Australians and Tasmanians of to-day, the "most archaic types" of humanity, are their nearest relatives, and yet these savages are not descended from the Neandertal men of Europe.

The face was singular, savage, usually more or less prognathous, and unlike that of any existing race. The nose was of unusual size and wide, the upper lip very wide, and at the base of the forehead there was a very prominent and continuous brow-ridge that extended from temple to temple. The lower jaw was heavy and massive and, as in the apes, was without a prominent chin. The brain was unusually large. The Gibraltar head, possibly of a woman, has a capacity of about 41 ounces, while the average of Neandertal skulls appears to be 49 (in one it is 53) ounces. This average is therefore greater than in the Australian and not much below that of Europeans, whose average capacity is about 49 ounces. The hair was probably wavy.

In at least two cases the skeletons were found in their original burial places, and from them we learn that they were laid away with their implements, paints, and food, indicating a ceremonial interment and offerings of food and implements to assist the departed in the spirit world.

The Man of Rhodesia. — In 1921, there was found in a bone cave at Broken Hill, northern Rhodesia, South Africa, an excellent human skull, besides other remains. The skull is of a radically different type from that of the African and European races of to-day, and nearest to the Neandertal skulls from Europe. The legs of the African man, however, were not bent as in the Neandertal people, but were straight and in all respects those of an ordinary modern man. The Rhodesian man (*Homo rhodesiensis*) is therefore not thought to be nearly so old as Neandertal man, although a first cousin of his; he is probably a modified "hold-over" into recent times. Keith thinks that Africa may well have been the cradle land whence were dispersed the Neandertal people.

Men of the New Stone Age

We are now to take up for study the dawn of human civilization, which began roughly about 18,000 B.C. in the Orient and probably in the lower and warmer lands to the south of the highlands of Asia

Minor and India. The Neolithic people of the city of Susa, Persia, appear to go back to 16,000 B.C. and the mid-sea peoples of Crete in the eastern Mediterranean to about 12,000 B.C.

The New Stone Age of human development emerges in latest Pleistocene time and continues into historic times. The stone culture is improving rapidly and is called *Neolithic,* since the chipping of the flints is of the highest excellence, and in addition, many of the weapons and tools are rubbed into shape and often polished. In the Neolithic period, next to food and clothing, the most important object to the men of the New Stone Age was flint. Flint mines were to them what iron mines are to us.

The peoples of the New Stone Age began to make pottery and introduced the herding of cattle and communal life. Later on, permanent habitations in stone huts and skin wigwams, along with agriculture, became more general, and their pottery was made more and more on the potter's wheel. Finally the metals, copper, gold, and iron, were introduced. Definite migrations and warfare began also with these peoples, and manufacturing and trading as well.

Aurignacian Man. — We now come to men of the human species (*Homo sapiens*) who at first were still hunters but who had far greater skill in the making of Paleolithic stone and bone implements than did their predecessors, the Neandertals, whom they dispossessed. They appeared in western Europe at about the close of the Glacial Period, or about 17,000 B.C. These people came from the east, spreading westward from Asia Minor, and their remains are found throughout the great part of western and central Europe and most of the Mediterranean countries.

There were at least two races of Aurignacians, a dominant one, the Crô-Magnon people, of tall stature, the men averaging over 6 feet in height, with long arms, and long in the lower leg. They were remarkably long-headed (dolichocephalic), with a large cranial capacity ranging between 52 and 56 ounces. The face was short, the eye orbits were wider than long and depressed, and the brow-ridges were strong. The other, or Grimaldi race, shows negroid characters, its members being but 5 feet 3 inches in stature (female) with extremely elongated lower limbs, flat nose, prognathous jaw, and slightly retreating chin. They are thought to be allied to the living Bushmen of Africa.

The Aurignacian races appeared throughout Europe at a time when the climate was colder than it is now and when the Neandertal men were vanishing. The animals of the chase living at that time were largely the reindeer and horse, and for this reason it is also spoken of

as the epoch of the reindeer. The Aurignacian implements are of the later Paleolithic type, that is, the workmanship of the flints is better and constantly improves with time, and the race had many more kinds of tools to serve more purposes. They also used bone for awls and ivory for skewers and ornaments, and made spears, bows and arrows, and fur garments. Themselves they ornamented with marine snail shells derived from the Mediterranean and the Atlantic, with fossil shells from far inland places, with teeth of mammals, and even with those of human beings, and later with beads, bracelets and other objects manufactured out of shell and ivory.

Armed with better weapons of the chase and a wider knowledge of their use, the Aurignacians were able to take better advantage of their environment. Under these circumstances, they had more ease and time for reflection, and we witness in them the birth of bodily adornment, clothing, and the fine arts. Their achievements along these lines excite the wonder and admiration of all anthropologists. Sculpture and drawing appear almost simultaneously, and later comes painting. This art we find preserved in the caves of France and Spain, the art of one period being overlaid by that of later times, and as time goes on the workmanship is greatly improved. No daylight penetrates into these deep caves, and as the walls are not smoked, it is believed that these early men had better methods of illumination than the torch; in fact, a few stone lamps like those made by Eskimos have been found. Animals of many kinds are depicted, at first as monochromes, the outlines done with charcoal (Fig., above), then engraved on the walls and even on the ceilings of the dark caves; later were added polychromes in red, brown, black, and several shades of yellow. The pigments were of mineral origin and were mixed with grease. These artists also engraved animals on stone, bone, and ivory. The human figure appears only in the later paintings, and in these are seen wigwams, garmented women herding cattle, and men dancing or chasing wild animals with dogs.

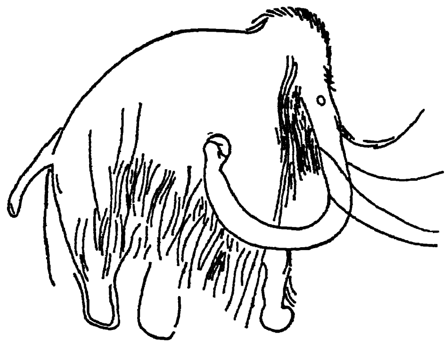

Fig. 237. — Painting of mammoth on cave wall at Combarelles, France. From George Grant MacCurdy.

The Aurignacians also laid away their dead with their ornaments of life, their flint tools, and the food needed for the journey into, or for use in, the life beyond.

Magdalenian and Later Races. — The Aurignacians were followed by the Solutréans and Magdalenians, men also of the Neolithic or polished stone period. These people not only made the same implements as the Aurignacians, but fashioned even better chipped flints and softer stones that were rubbed smooth and sometimes polished. The history of the race goes back perhaps 10,000 years, earlier than the most ancient monuments of Egypt or Chaldea, and while they too were hunters, they lived in wigwams and herded cattle, sheep, and goats, and somewhere about this time farming of plants for food had its origin.

During the later part of the New Stone Age, the climate moderated and became moister throughout Europe. This was the time of the Azilian peoples. With this climatic change came others among the plants and animals. The reindeer, the main source of food and clothing for man, vanished from all of southern Europe and retreated farther and farther northward as the continental glaciers melted away. With this amelioration of climate, man also spread northward following the reindeer, arriving in Denmark about 12,000 B.C., and in Sweden about two thousand years later. The climatic changes appear to have disestablished all organic nature, and in the greater struggle for existence a long night fell upon the progress of man, his skill, and his art.

The next great waves of progress, Evans tells us, came from two directions, first from the south through the valley of the Nile, and second from the Orient out of the valley of the Euphrates in Asia Minor. It was the Hellenic civilization that drew upon these sources, and it developed most rapidly in Crete, an outlier of Greece, where arose the Minoan civilization about 4000 B.C.

The use of metals first began in Egypt and Chaldea about 5000 B.C., when gold ornaments and copper implements and ornaments were made. This period is often called the *Age of Copper*, and was followed about 3000 B.C. by the *Age of Bronze*. These ages, however, have different dates in the various countries, the art arising in one and then slowly dispersing into ever wider areas. The Bronze Age arrived in central Europe about 2000 B.C. The *Age of Iron* had its rise in Palestine about 3200 years ago and the use of the metal then spread into India and to the Mediterranean peoples.

"Gold was the first metal used by man, and it was the arbitrary value attached to it for its supposed magical properties as an elixir of life that initiated the

world-wide search for it which has now lasted for sixty centuries. . . . The search for gold has been the most potent influence in the development and the spread of civilization. . . . Many other materials to which a magical or economic value was attached played a part in this process of exploitation. Resin, timber, pearls, copper, flint, jade, turquoise, lapis lazuli, amber, tin, and eventually all metals, were some of the more obtrusive lures that impelled men to embark upon any adventure, however hazardous; and the search for these things was responsible for the world-wide diffusion of culture." (Elliot Smith.)

Egyptian History. — Human evolution in the valley of the Nile begins with an old stone culture, followed by the crude Paleolithic implements found scattered abundantly over the desert, the makers of which are thought to have lived at least from 8000 to 6000 B.C.

The succeeding inhabitants of Egypt were the "Pre-Dynastic" people, a semi-civilized race of migrant hunters, herders, and farmers. They had no connection whatever with the older Paleolithic people of the desert. The date of their migration into the valley of the Nile appears to have been 4000 B.C. They inhabited the valley from the delta into Nubia and were related to the present Arabs and Berbers. This race, with a later admixture of Semites and a slight infusion of negroid elements, formed the foundation of the highly religious Egyptian people of the historic period. They brought with them a civilization in the Neolithic stage of stone culture. This culture was of the highest. Their clothing was made of coarse and finely woven linen. They made pottery and rudely decorated it, ground soft and hard stones into urns and ornaments, and of metals used sparingly gold, probably found in Nubia and the Soudan, and copper which appears to have been imported from Sinai. They also were familiar with the making of a vitreous glaze. They were, however, devoid of a written language.

Historic or dynastic Egypt begins with the first evidence of a crude pictorial language in the rule of King Menes dating about 3400 B.C. Civilization was rapidly developed during the first and second dynasties (3400–2980 B.C.), which gave rise to the "Old Kingdom" (III to VI dynasties), and the latter culminated about 2475 B.C. A marked civilization had been developed, in less than 1000 years, along with a well developed written language and the earliest large memorial and religious edifices, the pyramids.

Man in North America. — Many times during the past fifty years have the remains of fossil man been found in such geological associations as to lead their discoverers to assert the presence of man in North America, if not actually in the Pleistocene, at least in strata some thousands of years in age. According to the newer evidence interpreting the climate of the Pleistocene in this continent, the temperature began to become warmer less than 20,000 years ago. It now also appears that even before this greater change, the snow and ice had long been melted from the Cordilleran lowlands, thus permitting the migration of Asiatic peoples, animals, and plants into North America via a Siberia-Seward Peninsula land bridge. As the ice retreated northward from eastern North America, and with the continued amelioration of the climate, the red men or Indians

probably spread eastward and northward. Accordingly, the older records of man should be looked for along the Pacific coast and in the Southern States.

Mexican archeologists and geologists have long been calling attention to the occurrence of buried skeletons of man and something of his culture beneath from 15 to 30 feet of lava at San Angel, a southern suburb of the City of Mexico. These lava flows are believed to have taken place not less than 2000 years ago and it may have been even 10,000 years ago. To the northwest of this same city the identical culture is found beneath from 10 to 12 feet of sediments. On the other hand, the Aztec culture is modern since it occurs above lava flows and in the soil.

In 1916, Sellards reported the finding of human remains along with bits of pottery and charcoal at Vero on the Atlantic coast of Florida. The associated mammal bones were all of extinct Pleistocene forms, and this evidence appears to indicate about Middle Pleistocene time. The fossil plants, on the other hand, are of living species, and this evidence appears to Berry to indicate that the man of Vero is at best but a few tens of thousands of years old.

Ever since 1875 numerous argillite Paleolithic implements, and rare human bones, have been found deeply buried in the undisturbed gravel deposits of Pleistocene age at Trenton, New Jersey. In the upper one foot occur unmistakable Indian implements and pottery that are wholly unlike the implements of the deeper gravels. G. F. Wright and others are convinced that this evidence is unmistakable proof that man was present in North America toward the close of the Pleistocene.

It is a well known fact that throughout Pleistocene time mastodons roamed widely throughout the northern portions of North America, and that the last of them may have died out not many thousands of years ago in New York and Connecticut. Their bones are but little mineralized, and yet their ivory appears not to have been used by the Indians. In 1921, J. L. B. Taylor discovered in a Missouri cavern a leg bone of the Virginia deer "on one side of which is scratched a rude effigy of what unmistakably suggests an elephant" (Lucas). On the other hand, the Aztecs pictured elephant heads on the temple of Copan in Yucatan and the mound builders built elephant mounds in Ohio and Wisconsin and made pipes in catlinite shaped after the elephant.

John M. Clarke in 1887 dug up at Attica, New York, bones of the mastodon associated with bits of charcoal and pottery, and the late Professor Williston found in Logan County, Kansas, 20 feet beneath

the surface, an arrowhead that lay under a scapula of an extinct buffalo.

This and other evidence appears to place beyond doubt the probability that the mound-building Indians, mastodon, and a species of elephant lived together in North America not so very long ago. On the basis of the annually layered brick clays of the Hudson and Connecticut valleys, it would appear that this time dates back somewhere between 15,000 and 5000 years.

Birthplace of Man. — It is as yet impossible to say positively where man's transition from the ape to the human form took place. The oldest known bones of ape-man are those of *Pithecanthropus* found in Java, and for this and other reasons it has long been held that man probably arose in Asia and in the cooler climes rather than in the tropical jungle. We have seen that much of central Asia was being elevated in Miocene time and that the great Himalayas rose yet higher in the Pliocene and are still rising. This time and region were, then, critical for organisms, as the climate was changing from that of the tropics to cooler and finally cold conditions, bringing on great changes among the plants and thus reacting upon the animals. Man's ancestors, therefore, had to adapt themselves to these changing conditions, and in order to protect themselves against the cold, clothed their bodies in the skins of the chase, and because of this covering lost their bodily hair. In addition, they had to adapt themselves to the animals and plants that remained, and many of these are not only still living in this region, but are now domesticated. The ox (*Bos primigenius* into *B. taurus*), sheep, goat, pig, fowl, and pigeon are from India, while from wider Asia came the horse, camel, reindeer, elephant, peacock, goose, and ostrich. Still other forms reached Africa, and man there tamed the ass, domestic cat, greyhound, mastiff, and guinea hen. Of our domesticated plants the great majority are also of Asiatic origin. For these reasons it is thought that an ape line changed into man somewhere in central Asia, India, or China (Williston). However, the earlier evolution may have taken place in western Europe, since in England and Belgium are found the oldest human-made artifacts accepted by anthropologists as such.

Résumé

Man, like all other living plants and animals, begins in a single, tiny, nucleated cell, and his further development is that of the Metazoa (p. 672), and more especially that of the mammals and his nearest relatives, the apes. Something of this vastly long ancestral history is repeated in the first three months of each human being's existence and constitutes a metamorphosis far more wonderful and significant than the transformation of the caterpillar into the butterfly. In this development there is a fish-like stage, when the functioning heart and the vestigial gills are comparable to the same organs in fishes; then the heart is transformed into the type seen in amphibians, and next into that of mammals. At this time of development it is almost impossible to distinguish the human fœtus from that

of other mammals, but the latent ancestral history impressed upon the embryo from the very beginning goes on reproducing more or less blurred characteristics of the apes and man.

We have seen that the ape-man *Pithecanthropus* was in existence in the earliest Pleistocene, a time estimated by geologists to be somewhere between 400,000 and 1,400,000 years ago. This ape-man, however, was not in the direct line of evolution to man. Then there is no record of human bones for a long time, but as the true eoliths are of human workmanship, they are evidence of man's presence in western Europe since late Pliocene time.

About early Middle Pleistocene time, human bones are again in evidence, first in Germany in Heidelberg man, thought to be in the direct line with living men (*Homo sapiens*), and secondly in the dawn man (*Eoanthropus*) of England, who is not in direct ancestry with the men of the present. Later than either of these ancestral men are the Neandertal people, who are also not directly related to *Homo sapiens*. They made their appearance probably 150,000 years ago and lived almost into modern times; their remains are widely scattered throughout western Europe (Fig., p. 680). In all of these ancient men mentality was of slow growth, and yet as early as late Pliocene time, man in England knew how to kindle fire. The Neandertal men also made fires, and had a religious instinct, seen in the respect paid to the departed by laying them away in graves with ceremony. With the appearance of the Aurignacians about 20,000 years ago, the present size of the brain was attained. Human society and primitive farming had their rise about 10,000 years ago.

Future Human Progress. — Human mentality now dominates the organic world, and to it all creation will soon be more or less subservient. Through his inventions, man will eventually control his environment and largely nullify the laws of natural selection and survival of the fittest to which all other organisms are subject. His future progress, however, is dependent upon himself, dependent upon whether he will learn to control himself for the benefit of human society, as the clashings of men and human civilizations are still due to his inborn " predatory instinct."

Human progress has been along three main lines of evolution, namely (1) bodily, (2) intellectual, and (3) social. Conklin says that during the last 20,000 years man has made no very marked progress in his bodily evolution, and that intellectually it is a question whether he is as far advanced as were the ancient Greeks. Future progress is therefore dependent upon the progress of human society through coöperative effort. Through careful breeding man

can eliminate the unfit and undesirable, and raise the human stock to the level of the best of existing individuals.

"To us it is given to coöperate in this greatest work of all time and to have a part in the triumphs of future ages, not merely by improving the conditions of individual life and development and education, but much more by improving the ideals of society and by breeding a better race of men who will 'mould things nearer to the heart's desire'" (Conklin).

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